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JOHN F. DASHIELL, *Editor*

The Differential Effects of Cortical Injury and Retesting on Equivalence Reactions in the Rat

By

SEYMOUR WAPNER

University of Rochester

A dissertation submitted in partial fulfillment of the requirements for the
degree of Doctor of Philosophy in the University of Michigan.

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INTRODUCTION

IT HAS long been recognized that psychological descriptions purely in terms of objective stimulus and overt response fail to take into account the selective action of the animal as a perceiving organism. It cannot be assumed that all stimuli to which an organism is exposed are effective, any more than it can be assumed that all impulses achieve expression in overt behavior. The study of equivalence behavior is important because it enables us to make a searching analysis of the results of the selective processes, particularly on the stimulus side.

Klüver (19) and Lashley (37) have pointed out that equivalence may be studied on the response side as well as on the stimulus side of behavior, and Klüver (19) has indicated that stimulus equivalence has no logical precedence over motor equivalence, but that the former has been explored more intensively because it is more accessible as a starting point.

Klüver (15, 16, 17, etc.) who has done the pioneer work in this field was concerned mainly with developing the method which makes use of equivalent stimuli and with accumulating data on equivalence behavior in order to throw light on behavior mechanisms. He also emphasized the importance of equivalence behavior for neuro-behavioral and neuro-physiological theory. Lashley (30, 31, 34, 37) interested in these latter aspects has utilized functional equivalence concepts in his program of exploring the relation between neurological and psychological phenomena.

The problem of equivalence depends upon similarity in reaction or "meaning" to objectively different stimuli. The

similarity in effect is due, presumably, to some essential psychological identity of the two objectively different stimulus patterns. Equivalent stimuli are defined in terms of the reaction elicited by a particular organism. On the one hand, two or more stimulus patterns which differ objectively in certain respects but nevertheless elicit responses which are the same are said to be equivalent. On the other hand, any two objectively different stimuli failing to produce responses which are for all practical purposes identical are considered non-equivalent.

The method of equivalent stimuli developed by Klüver (15, 16) consists in observing equivalence reactions under carefully controlled conditions, and is applied in the following manner. A definite response to a particular stimulus is taken as the starting point. This response may be either learned or unlearned, but it must appear consistently whenever a given animal is confronted with a particular stimulus. The animal is next presented with one or more new stimuli, called critical stimuli, in a free choice situation. These critical stimuli are similar to the stimulus situation calling out the original response in certain respects, and different in others. If the animal consistently makes the same reaction to any of the new stimulus configurations that it did to the original stimulus configuration, then these new configurations are said to be equivalent to the original. If the same response is not maintained, the new stimulus configuration is said to be non-equivalent.

By careful study of the critical stimuli which are reacted to as equivalent and those which are reacted to as non-

equivalent, it may be possible to discover properties which the equivalent stimuli have in common with the original stimulus configuration, but which do not appear in critical stimuli regarded by the animal as non-equivalent. If any such properties are discovered, it may be concluded that of all the possible features of the original stimulus configuration which might characterize the stimulus objectively, the animal relies on those properties which the original stimuli have in common with the equivalent stimuli. Thus, at the end of an experiment by this method we have achieved a more accurate idea of what the stimulus "means" to the animal than would be possible in any other way.

When the method is applied to many individuals and the results are analyzed by statistical methods, it should be possible to make certain general statements as to the characteristics of a stimulus which are likely to be most important in the perceptual or behavioral world of the animal form in question. It can be seen that the method is highly individualized and therefore time consuming. However, because it is the only method which can be applied to a variety of animal forms to obtain just this kind of information, it is essential for any thorough-going analysis of behavior. As might be expected the method has found application in many fields of psychology, particularly perception, personality, learning, the so-called higher mental processes, and in the correlation of neuro-behavioral data.

If it be conceded that there is no strict correspondence between the behavioral and the geographical environment, the method of equivalent stimuli has an immediate application in providing us with a method of exploring the nature of the behavioral world of the various animal

forms. The method of equivalence aids in characterizing the discrepancy between the phenomenal world and the objective world as a consequence of the contribution of the individual organism. Klüver (17) gives an extensive bibliography of studies which have utilized the method of equivalent stimuli in perceptual problems, and has summarized some of the literature on the subject (19). Using the method of equivalent stimuli, considerable progress has been made in studying the perceptual world of many different animal forms, e.g., fish (Mesters, 50), toads (Buytendijk, 1), rats (Lashley, 36; Maier, 43, 45), dogs (Sarris, 56), monkeys (Klüver, 17, etc.).

In close connection with the work on perception is the excellent use that has been made of the method of equivalent stimuli in the study of personality and psychopathology. Klüver (19) has summarized some of this work and has indicated that the *Zuordnungsmethode*, first suggested by Wertheimer, which includes all forms of category behavior tests, is an application of the method of equivalent and non-equivalent stimuli. The work of Goldstein and his collaborators (e.g., 6, 7, 8) on pathological cases, of Strauss and Werner (60) on endogenous and exogenous mentally retarded children, and of Halstead (10) on brain injured and normal adults are examples of the valuable use that such methods have in studying personality and psychopathology.

In addition the method is valuable because it gives us insight into problems which are important for learning and learning theory. It may give us an answer to the question of *what* has been learned. It may give us an answer to the question of whether a discrimination has been made in terms of absolute or relative properties. It throws light on the prob-

lem of transfer of training (Maier and Schneirla, 48; Klüver, 17). Its importance for learning theory has already been recognized by Klüver (17), Lashley (34), Maier and Schneirla (48), Tolman (61), Hull (13), and others.

The topics of generalization, concept formation, and abstraction have been given much space in the experimental literature. These experiments have been marred by considerable confusion as to terminology, and doubt as to interpretation. Nevertheless, considerable interest attaches to them because they have been designed to discover the occurrence of "higher mental processes" at various phylogenetic levels. Discussion of them is relevant here because, as certain critics have indicated, many of the experiments which purport to investigate these so-called "higher mental processes" have been designed in such a way that they amount to nothing more or less than experiments in equivalence behavior.

For example, Klüver (17) states:

If a monkey reacts to stimuli which can be characterized as belonging to a large number of different "dimensions," and if in doing so he reacts consistently in terms of one relation, let us say, in terms of the "larger than" relation, he may be said to "abstract." The fact that widely different stimulus situations may be equivalent can be understood only by assuming that one characteristic or set of characteristics is "abstracted." In this sense a large number of our experiments may be considered "abstraction" experiments. These experiments show that the monkey is capable of what has been called an "abstraction of dependent elements of perception." . . . But this statement, it would seem, is of interest only in so far as it represents a novel way of describing certain equivalent reactions (p. 326).

Maier and Schneirla (48) analyzed the experiments of Fields (3), Gangerelli (5), Kroh (29), Robinson (55), and Gellerman (4) from the same point of view in con-

siderable detail, and likewise pointed out that, properly considered, many of the abstraction experiments can be adequately understood if they are considered as equivalence experiments. Smith (57) agrees with Klüver and Maier and Schneirla, and indicates that the results on equivalence may be important for the interpretation of abstraction and related concepts.

Equivalence reactions have also been used to great advantage in neuro-behavioral studies. In this connection, Lashley (34) utilized equivalence behavior in a theoretical controversy as to the manner in which positive transfer can be explained: whether or not it occurs as a result of the involvement of identical nerve cells. Now, if positive transfer occurs between stimuli having no elements identical with the original stimuli, then it is impossible that the neural elements involved should be identical for the two cases and transfer must be explained on other grounds. Equivalence work offers many instances of just this nature, as Lashley (34, 36, 37) and McKinney (49) have demonstrated in special experiments. Many other equivalence experiments such as those of Klüver (17) and those of Maier (43, 45) can also be adduced as supporting evidence. The mere occurrence of equivalence behavior has served to discredit any neurological theory of transfer which depends upon identical neural elements. The students of neuro-behavioral problems are now faced, however, with the question as to the manner in which equivalence behavior *can* occur.

Lashley (37) has recently criticized some of the neuro-behavioral theories developed to explain stimulus equivalence (e.g., Pavlov, 53; Spence, 58; Hull, 13; Köhler, 25; Lashley's earlier theory, 31). In this article (37), he has also pre-

sented a theory to explain stimulus equivalence based upon the anatomic studies of Lorente de Nó (39), and a rough analogy of the nervous impulse in the brain with wave motion in a homogeneous liquid. The theory is presented as an hypothesis which is amenable to experimental verification; its worth can only be indicated by further experimentation, which still remains to be carried out.

From other theoretical backgrounds, however, neuro-behavioral experiments have already been carried out which aim to study the gross effects of brain lesions on equivalence behavior. Klüver and Bucy (23) studied the effect of removal of the temporal lobes in monkeys. Differential responses to form, established pre-operatively, were disturbed after bilateral temporal lobectomy, although it was possible to reestablish the response by further training. But most important, from the present point of view, these investigators were able to demonstrate that the animals had not lost the ability to "generalize" when responding to visual stimuli.

In the "form board" tests the properties of the stimuli were changed by introducing variations in size, brightness, color, and even shape (by presenting for instance an ellipse and a triangle instead of a circle and a square) or by substituting "figures" drawn on a cardboard for a circle and a square. Despite these changes all three monkeys continued to react positively to the curvilinear figure (23, p. 995).

In a recent article (22), Klüver summarized his previous work (17, 18, 20, 21) and some previously unpublished experiments on the visual functions after removal of the visual areas. Those pertinent to the present study will be mentioned below.

Klüver found that a monkey which had undergone bilateral occipital lobec-

tomy prior to training and which had then been trained to respond positively to the brighter (less bright) of two areas of the same size, would respond positively to the larger (smaller) of two equally bright areas when they differed in size. This would indicate an equivalence of brightness and area. Furthermore, Klüver noted: "If the stimuli differ in both brightness and area, the response is determined by differences in the density of luminous flux entering the eye" (22, p. 267).

In other experiments Klüver found that when two stimuli differ in duration of exposure but are equal with respect to area, brightness and distance from the eye, the time factor determines the response. If in such a case, a monkey which had undergone bilateral occipital lobectomy was trained to respond positively to a brighter stimulus, under these conditions it would choose the stimulus exposed for a longer time. When stimuli differ with respect to brightness, area and duration, the response is determined by the total quantity of light entering the eye.

The monkey which has undergone bilateral occipital lobectomy is, like the normal monkey, able to respond to the relatively larger (smaller), or the relatively brighter (less bright) of two stimuli, but the operated animal transposes in terms of the total quantity of light received at the eye, while the normal animal relies more on actual brightness differences. Apparently "... removal of the occipital lobe definitely abolishes brightness vision and leaves only responses in terms of quantity of light entering the eye intact" (22, p. 274).

The most important fact gathered from these experiments from the present point of view is that the operations—temporal lobectomy or occipital lobec-

tomy—apparently do not destroy the ability to respond to similarities in heterogeneous situations, but the nature of the similarities to which these animals respond may change markedly. It would be theoretically significant if the inference from this result, that the ability to “generalize” is maintained even after operation, could be demonstrated in forms like the rat which are lower in the phylogenetic scale than the monkey.

There is some limited evidence which suggests that the rat is capable of such “generalization” after operation. Hebb (11) trained normal rats and rats with striate area destruction to discriminate brightness in a discrimination box. Critical tests were carried out using the positive intensity, and a new intensity which had the same relation to the positive that the positive had formerly had to the negative. Both normal and operated rats transferred their acquired response to the new stimulus. This was taken as an indication that the rats were discriminating relative rather than absolute intensities.

Maier (45) studied the effect of cortical injury on equivalence reactions in rats. The animals were trained to discriminate two figures (equal size) differing in figure-ground relations. The positive card contained a black circle on a white ground and the negative card contained a white circle on a black ground. After learning the discrimination, the animals were given free choice tests on 13 critical pairs of cards, which differed in size of figure, brightness relations, and figure-ground brightness relations. To determine the effects of partial decortication and retesting on equivalence choices exhibited during the critical tests, the animals were divided into three groups: (1) those tested on two separate occasions

and not subjected to cortical injury; (2) those tested before and after cortical injury; and (3) those tested after cortical injury only.

Using this experimental design Maier found that cortical injury was associated with an increase in number of equivalent stimuli chosen, and retesting was associated with a decrease in the number of equivalent stimuli chosen. There was evidence of a positive relationship between extent of cortical injury and the number of equivalent pairs chosen after operation. On analysis, certain of the critical pairs proved especially diagnostic, in the sense that they were dropped as equivalent by the normal animals and added as equivalent by the animals retested after operation. These data were used as evidence that retesting produces an increase in the tendency to react to difference, i.e., an increase in the importance of the absolute properties of the training pair. The effects of cerebral injury, however, were considered to indicate an increase in reactions to likeness and decrease in reactions to difference, i.e., an increased importance of the general and relative features of the training situation after operation.

Reactions to likeness and reactions to difference were considered as two separate processes, the former being more primitive. Maier interpreted the number of equivalent stimuli chosen a product of either: (1) reactions to likeness, or (2) abstraction, which was regarded as a balance of reactions to likeness and difference.

There are certain limitations to Maier's study. For example, Maier suggests that the trends observed in his study must be duplicated before they can be regarded as holding generally. It should also be noted that Maier's analysis for the most part employed only

one gross measure, number of equivalent stimuli, and therefore was not specifically adapted to discovering the importance of relational properties in determining equivalence responses, although his results (and those of Klüver, Klüver and Bucy, and Hebb) indicate that they may have an essential role. Further, Maier's analysis did not reveal any specific aspect of the stimulus pair determining the

reaction. Maier recognizes that a longer and more diagnostic series of critical pairs would be necessary to determine whether the rat transfers its response in terms of a single property.

The questions raised by the neuro-behavioral experiments of Klüver (22), Klüver and Bucy (23), Hebb (11), and Maier (45) served as a point of departure for the present investigation.

PURPOSE

THIS investigation was designed, first, to discover the nature of equivalence reactions in normal animals which had learned a "size" discrimination, and how these equivalence reactions are altered with retesting.

Secondly, it was designed to find out how cortical injury affects the equivalence reactions of rats which had learned a "size" discrimination.

Thirdly, an attempt was made to construct a highly diagnostic series of critical cards, which would indicate properties serving as a basis for the discrimination, and which would also serve to test the role of relational responses.

Finally, an effort was made to determine whether alterations in procedure have any effect on equivalence reactions. The particular factors chosen for variation were the training procedure, and the order of presentation of critical pairs.

THE DIFFERENTIAL EFFECTS OF CORTICAL INJURY AND RETESTING OF EQUIVALENCE REACTIONS IN THE RAT

PROCEDURE

I. APPARATUS AND MOTIVATING FACTORS

A. Apparatus

A MODIFICATION of the Lashley jumping discrimination technique was used in this experiment. The technique requires the rat to choose between two stimulus cards which differ in pattern. One of these, the positive stimulus, is unlatched, and leads to reward; the other, the negative stimulus, is latched, and leads to punishment. The only essential feature in which the jumping stand used differed from that originally described by Lashley (32) was in the substitution of an electric grid for the jumping platform.

The stimulus patterns were painted on dull-mat cellulose paper and mounted on six-inch squares of heavy cardboard. This provided a non-glare surface that could easily be washed. Since different stimulus cards were used in different parts of the experiment, they will be described in the appropriate places.

B. Motivating Factors

The nature of this technique is to provide reward for a correct choice and punishment for an incorrect choice. If the rat chooses the correct card, he obtains food, and does not fall; if he chooses the incorrect card, he gets no food, and suffers a fall. Twenty-four hour hunger motivation was used.

In cases where the rat did not jump after he had been facing the cards for 30 seconds, the grid which served as a jumping platform was electrified, and the rat received a shock. This operated only to force the animal to leave the

platform, and presumably did not favor either the positive or the negative card (Maier, 44).

II. EXPERIMENTAL PROCEDURES

The experimental procedure was divided into three parts. (1) The preliminary period was devoted to familiarizing the animals with the situation and teaching them to jump. (2) During the training period the animals learned a discrimination. (3) In the critical series, from which the most important data are derived, the attempt was made to determine the basis for the learned reaction by the method of equivalence. This involved a free-choice situation with 23 pairs of critical cards, with the training pair presented at intervals to make certain that the learned reaction was kept intact throughout the test.

A. Preliminary Period

The animals were fed on the food platform for a period of two weeks during which time they became accustomed to it as a feeding place, and became familiar with the apparatus through exploration.

At the end of two weeks the animals were taught to jump by a gradual process. At first the jumping platform was moved so that the gap between it and the food platform was closed to one inch and the animals could walk through the open windows from the jumping platform to the food platform. Gradually the gap was increased to a maximum distance of 20 centimeters. While the animals were first learning to jump, there were no cards of any sort in the

windows. Later all rats were trained to jump through black cards. During the entire preliminary training period the animals were guided so as to prevent them from developing a consistent preference for either of the two windows.

B. Training Pair and Techniques

The animals were required to learn a simple discrimination, and it was this discrimination for which equivalence reactions were later studied intensively. One card of the pair had a 12 cm. black circle on a gray background, the other had a 6 cm. black circle on a gray background (Plate 1). All animals were required to make a positive response to the card containing the larger figure. Inasmuch as Maier (43) using the same training pair clearly showed that the preference of the animals on the critical series depended on the member of the training pair made positive rather than some innate preference of the animal, all rats were trained to respond positively to the same card. To make sure that the rats chose on the basis of pattern rather than position, the position of the correct card was varied from left to right according to a prearranged chance order.

Two training techniques were used. In the "single-jump" technique, the training pair was always presented ten times a day. Each animal was permitted one jump for each presentation, regardless of whether he made a correct or incorrect choice. After each presentation the position of the cards was changed or remained the same, depending upon what was indicated in the prearranged chance order. If an animal persisted in making incorrect responses by the 200th trial (i.e., reacted continually in terms of position, or to the negative card), manual guidance was introduced on the

201st trial and was applied when necessary until the rat began to master the required discrimination (see Maier, Glaser and Klee, 46).

The "multiple-jump" technique offered the rat an opportunity to correct his own mistakes within each trial. If, at the beginning of a day's run, the animal was confronted with the positive card at the right and made a correct choice, the cards were immediately changed for the next trial, just as would be the case for a corresponding situation in the single jump technique. However, if the animal made an error on his first jump, the trial was not considered ended, and the animal was replaced on the jumping platform for another attempt. This was continued until the animal made either a correct choice or a series of five successive incorrect choices. In the latter case, the animal was guided by the experimenter to the correct card on the sixth jump. Then the trial ended, and the cards were changed. Thus, every trial ended with a correct jump, either spontaneous or guided, and the training pair was presented a variable number of times with a minimum of 10 times and a maximum of 60 times per day. The exact number of jumps per trial depended upon the rat's mastery of the discrimination, so that when the discrimination was learned, each trial consisted of one correct item, and the number of jumps was reduced to 1 per trial, or 10 per day. Because a trial might vary in length from 1 to 6 jumps, this technique is hereafter referred to as the multiple-jump technique, in contrast to the single-jump technique, where there was a limit of 1 jump per trial. Approximately half the rats learned with the single-jump technique; the others learned with the multiple-jump technique.

In both techniques all errors were recorded as well as the number of guided jumps to the positive card. The discrimination was considered mastered when the animals reached a criterion of 3 consecutive errorless days of 10 trials per day.

C. Critical Series

As soon as the learning criterion for the training pair (Plate 1) had been reached, the rats were started on the critical series. The critical series consisted of 23 pairs of cards. The individual cards varied in size of the figure, the total amount of light reflected, the brightness of the figure and the brightness of the background. These cards in the combinations used are reproduced in Plate 1.

The critical pairs were arbitrarily divided into two sub-series: sub-series A, consisting of 10 pairs, and sub-series B, consisting of 13 pairs. The subdivision was made in order to discover whether order of presentation affected the equivalence reactions. Approximately half of the animals were tested on sub-series A first, and sub-series B second; the others were tested with sub-series B first, and sub-series A second. At the end of the series each rat had been tested with all 23 pairs of cards. Whenever a critical pair was presented, both cards were unlatched, and as a consequence, whatever choice the rat made was rewarded.

The daily program consisted of 2 presentations of the training pair (with relative positions alternated); 1 presentation of each of 2 critical pairs; 2 presentations of the training pair; 1 presentation of each of 2 other critical pairs; 2 presentations of the training pair; 1 presentation of each of 2 still different critical pairs; and finally 2 presentations of the training pair.

Thus, there were 14 jumps per day providing the rat did not break down in the discrimination of the training pair. If the rat did break down, i.e., jump to the negative card of the training pair, the day's program with the critical series was interrupted and he was immediately retrained with the training pair to a criterion of 10 consecutive errorless jumps. When this criterion was reached, the day's program with the critical cards was resumed. Each time the rat had a breakdown, he was retrained, though there might be several breakdowns per day. This care in keeping the original discrimination intact is of course essential in any study of equivalence reactions.

Since reactions to the critical pairs furnished the basis for judging equivalence, it was decided to present each pair 6 times to each rat. Inasmuch as 6 critical pairs were presented each day, this was achieved by giving each animal 10 days on sub-series A cards (10 pairs), and 13 days on sub-series B cards (13 pairs).

Where the order was A-B, 6 presentations of all A pairs were given before beginning on any B pairs, and in the case where the order was B-A in the same way 6 presentations of all B pairs were given before beginning on any A pairs. This makes it possible to compare the initial part of the critical series with the latter part to see whether a change in reaction occurred during the course of the testing program. It is impossible to make a more detailed analysis of order of presentation than gross comparisons of the results for each sub-series, because of the method used to prevent the anticipation of specific serial associations from one pair to the next, which might otherwise occur because there were at least six presentations of each

critical pair. Serial associations were prevented by presenting, e.g., the sub-series A pairs in a specific order and then running through these same pairs five more times, changing the order each time in a uniform way for all animals. After the six tests for each pair belonging to sub-series A were completed, a corresponding procedure was carried out for the sub-series B pairs, following which any questionable pairs were tested.

Once the rats had completed 6 trials with each of the 23 pairs, there was some basis for judging equivalence or non-equivalence. A 6 to 0 choice in favor of a particular card of a critical pair was taken as showing equivalence, i.e., a definite preference for this card as a result of experience with the training pair (Maier, 43). A 3 to 3 distribution of choices to the two cards of a critical pair was taken to indicate non-equivalence, i.e., experience of the training pair was ineffective in producing a differential response. A 4 to 2, or 5 to 1 distribution of choices to any pair was considered questionable, so that further tests were made. Where 4 to 2, or 5 to 1 distributions occurred, 6 more presentations were given of the particular critical pairs in question, so that there was a total of 12 reactions on which to calculate equivalence or non-equivalence of questionable pairs. Questionable pairs which upon retest showed ratios of choice of 11 to 1, 10 to 2, 9 to 3, and 8 to 4, were regarded as equivalent. The one exception to this classification was the ranking as non-equivalent, the 8 to 4 ratios in which the retest choices had been in the ratio of 3 to 3. The first six choices established different equivalent, non-equivalent and questionable pairs for different rats, so that on the series of 6 additional trials with questionable pairs, the specific pairs presented varied,

depending on the equivalence reactions the individual had already shown. To summarize, the judgment of equivalence was based on a minimum of 6 or a maximum of 12 presentations of each of the 23 critical pairs, and any given rat might have received 6 presentations of certain pairs, while he received 12 presentations of others.

III. GROUPS AND TREATMENT

Forty-seven albino rats, both male and female, from 4 to 6 months of age, taken from the stock of the Laboratory for the Study of Abnormal Behavior of the University of Michigan were used in this experiment. During the course of the experiment, in accordance with one of the major purposes of this investigation, the rats were divided into three groups to study the effect of cortical injury.

A Normal Group (Group I—15 rats) learned the discrimination, and was tested on the critical series in accordance with the procedure already described. Then they were given a 14 day rest, following which the same procedure was repeated, i.e., they were retrained on the discrimination, and then retested on the critical series.

A Post-operated Group (Group II—15 rats) learned the discrimination and was given a first test on the critical series in the same way as the Normal Group. They were then subjected to brain injury, allowed 14 days as a recovery period, and then retrained on the discrimination and retested on the critical series.

A Pre-operated Group (Group III—17 rats) was first subjected to brain injury, and then put through the training and the critical series (one test).

Actually the animals of the Post-operated Group were treated in an identical fashion with the animals of the Normal Group up until the completion

of the first test. The total number of normal animals for which results were obtained on the first test was 30. After the first test was completed, these 30 animals were separated into two groups, fifteen of the animals remained normal before retesting (Normal Group), and fifteen were subjected to cortical injury before retesting (Post-operated Group). The attempt was made to equate the Normal Group and the Post-operated Group by separating the originally normal 30 animals on the basis of total number of equivalent pairs chosen during the first test occasion. But at the same time it was necessary to have an equal number of animals trained by the two training techniques, and having the same order of presentation in each of these major groups. The following is an example of an ideal case of equating the groups. If two of the 30 animals chose 11 pairs as equivalent on the first test, and if each of the animals was trained by the same training technique, and had the same order of presentation of critical pairs, then one of those animals was made a member of the Normal Group and the other a member of a Post-operated Group. The attempt was made to approach this ideal as closely as possible. Thus for both the Normal Group and the Post-operated Group ap-

proximately half of the animals received the A-B order of presentation and the remainder the B-A order of presentation. And further each of these was subdivided again so that approximately half were trained with the multiple-jump technique and the remainder with the single-jump technique.

The Pre-operated Group was also equated with respect to the variables of training technique and order of presentation, so that approximately half of the representatives of this group had one kind of training, and approximately half had one order of presentation.

The rats were run daily, except for irregular vacations which were never more than 2 consecutive days in length. The entire experimental program occupied 21 months.

The operations were performed under deep ether anaesthesia by thermocautery applied to the skull, in all but 5 cases which were trephined.

On completion of the experimental program, operated animals were sacrificed and their brains removed for histological study. To determine the locus and degree (depth and area) of lesion, the brains were embedded in celloidin, sectioned, stained with iron hematoxylin, and reconstructed in accordance with Lashley's technique (30).

RESULTS

I. EFFECT OF VARIATION IN PROCEDURE

THE first main problem was to determine how equivalence reactions were affected by variations in the experimental procedure. The factors chosen for variation were: (1) the training schedule; and (2) the order of presentation of the critical pairs. For this purpose sub-groups were arranged, as described in the section on procedure, in order to compare the single-jump versus the multiple-jump techniques, and further sub-groups were arranged to compare two orders of presentation of the critical pairs, A-B, and B-A.

These comparisons are considered first because if no significant differences appear between the sub-groups, they can be recombined in making later comparisons between the main groups.

and comparisons based on the equivalence ratings of the cards would show differences in the nature of the discrimination learned; while comparisons based on the number of breakdowns would show differences in the stability of the learning.

Accordingly, for the study of the first index, number of equivalent pairs, the following analysis was made. The equivalence scores for *all* test occasions regardless of other factors were divided into two categories on the basis of whether the score was obtained from an animal trained by the single-jump technique or the multiple-jump technique. All animals except those in the Pre-operated Group contributed two tests to the total number of tests. The two groups obtained on this basis were then compared

TABLE I
Effect of training technique on behavioral criteria

Criterion	Single Jump (Mean)	Multiple Jump (Mean)	Mean Difference	Degrees of Freedom	t	Probability of Occurrence by Chance
Number of Equivalent Pairs	10.0 N = 35	8.9 N = 42	1.1	>30	0.733	44%
Number of Breakdowns	0.21 N = 35	0.19 N = 42	0.02	>30	0.488	63%

A. Training Schedule

Three indices were used to discover whether there were any significant differences between the behavior of animals trained by the multiple-jump technique and those trained by the single-jump technique. The three indices were: (1) the number of equivalent pairs chosen in the critical series; (2) the equivalence rating of each pair; and (3) the number of breakdowns in learning. Comparisons based on the number of equivalent pairs,

in terms of the average number of equivalent pairs per test, as shown in Table 1. Although there is a slight tendency for the animals in the single-jump group to regard a greater number of pairs as equivalent, the difference between the mean number of equivalent pairs for the two groups is not significant.¹ That is, there is no evidence from

¹This tendency of the single-jump animals to react to a greater number of pairs as equivalent is interesting in relation to the possibility that the animals of the single-jump group developed

the number of equivalent pairs chosen that training procedure affected the nature of the discrimination in the course of the original learning.²

A different use can be made of the number of equivalence reactions by comparing *change* in number of equivalent pairs from the first to the second test. Such comparisons were based on the total number of animals which received two tests (Normal and Post-operated Groups). In computing the *change* or mean increase in equivalence score for the single-jump animals, the number of equivalent pairs chosen on the first test was subtracted from the number of equivalent pairs on the second test. The same procedure was carried out for the multiple-jump animals. Both the single-jump and multiple-jump animals showed a mean increase of + 2.0 equivalent pairs. Thus the difference in training does not produce a difference between the mean increases in equivalent pairs.

In summary, both applications of this index, number of equivalent pairs failed to show that there was any effect of the difference in training technique.

Having shown that the rats trained by the two techniques chose the same number of equivalent pairs, it is necessary to determine whether or not these choices were distributed in the same way

among the critical pairs by the single-jump and multiple-jump animals. Therefore, the second index chosen for comparing the two training techniques was the equivalence rating of the critical pairs. The equivalence rating for a particular pair of cards was determined by finding the percentage of animals that regarded it as equivalent to the training pair. When based upon the choices of any particular group of rats, the equivalence ratings of all of the pairs will form a series or rank order according to the frequency with which they were chosen as equivalent by the animals of the particular group. The same pair may have a different rank when based upon the reactions of one group than when it is based upon the reactions of another group. Thus the rank order for the whole series of cards can be determined for different groups of rats and can be compared by correlation technique.³ The equivalence ratings for the single-jump sub-group and the multiple-jump sub-group were based upon the total number of tests. All animals except those in the Pre-operated Group contributed two tests to the total number of tests.

If the equivalence reactions to the critical pairs were distributed in the same way, regardless of single-jump or multiple-jump training, the correlation between the equivalence ratings of the two sub-groups would be positive and high. If the equivalence choices of the two sub-groups were distributed differently, the correlation would be positive and low, or zero, or negative.

The correlation of the equivalence ratings of the pairs for the single-jump sub-

fixations of the discrimination (Maier, Glaser, and Klee, 46). This discrimination was very difficult and may have had somewhat of the frustrating effect of an insolvable problem. The idea that the discrimination might have functioned as an insolvable problem receives support from the fact that all animals learning by the single-jump technique had to be guided after 200 trials before mastering the discrimination. On the other hand, evidence opposed to this line of thought is presented later in connection with the discussion of breakdowns (see p. 15).

² That the groups are of similar composition with respect to number of equivalent pairs chosen is further indicated by the lack of significant difference in variability of number of equivalent pairs for the two groups.

³ Throughout this study the correlations were calculated by the method of rank difference, $q = 1 - 6\sum D^2 / N(N^2 - 1)$. The probable error of q was calculated by the following formula: P.E. $q = .7063(1 - q^2) / \sqrt{N}$.

group versus the multiple-jump subgroup was $+.92 \pm .02$. This high reliable positive correlation shows that the rats from the two training sub-groups distributed their equivalence choices in the same way among the critical pairs, and therefore, no distinction between the groups should be made on this basis.

Taken together, the evidence from the number of equivalent pairs chosen and from equivalence rank shows that no difference in the nature of the discrimination learned can be attributed to the difference in training technique.

Although there is no difference in the nature of the discrimination learned, there exists a possibility that one training technique might have contributed to more thorough learning of the original discrimination than the other, i.e., there might have been a difference in the stability of the learning, which would subsequently have an indirect effect on equivalence reactions in the critical series. To test this possibility, the single-jump and the multiple-jump sub-groups were compared by a third index, the average number of breakdowns.

The average number of breakdowns was calculated by dividing the total number of breakdowns for any given rat by the total number of days which the rat spent on the critical series. This gives the average number of breakdowns per day of critical trials, or a breakdown score for each animal. The average score for all single-jump animals on each test occasion was compared with the average score for all multiple-jump animals on each test occasion (Table 1). While the animals of the single-jump sub-group have more breakdowns on the average than the multiple-jump sub-group, the difference⁴ is not significant.

⁴In reference to the possibility discussed in

Since none of the three indices used to study the effects of training technique offer any basis for supposing that a difference in training technique produced a difference in what was learned in the discrimination, it will be justifiable to combine these sub-groups in making later comparisons.⁵

B. Order of Presentation

Whereas the previous discussion was concerned with situational factors operating during the learning period, the second variation order of presentation of critical pairs was concerned with factors operating during the period of testing with the critical series. In addition to showing the effect of variation in procedure during this period, the division of the main groups into sub-groups having different orders of critical pairs served as a necessary control.

Comparisons showing the effect of order of presentation on the average number of equivalent pairs chosen are given in Table 2. The equivalence scores for sub-series A pairs are compared for the two groups of animals, one to which it was presented first, and the other to which it was presented second. The corresponding comparisons are given for sub-series B pairs. Each test of all ani-

footnote 1 on p. 13 that the single-jump animals may have fixated the discrimination, the data presented here militate against such an hypothesis. If the discrimination had been fixated by the single-jump animals, one might expect them to show fewer breakdowns on the critical series than the multiple-jump animals. In general the reverse is true.

⁵When the data are fractionated on the basis of the major groups, Normal, Post-operated and Pre-operated, and the single jump and multiple-jump animals compared within each major group, the results are the same. This eliminates the possibility that the lack of difference between sub-groups was obtained because of a complication from the major variables, i.e., operation and retesting might have worked in opposite directions, and so concealed a difference.

mals was used in calculating the average number of equivalent pairs. Examination of Table 2 shows that there is no significant difference in the mean number of equivalent A pairs chosen with the different orders, and the same is true for the sub-series B pairs.⁶

Not only are the differences insignificant, but they show no evidence of a consistent direction or trend. Order of presentation does not seem to affect the mean number of equivalent pairs chosen.

The next step is to determine whether order of presentation affects the distri-

The correlation between the equivalence ratings of the sub-series A pairs when presented first versus when presented second was $+.83 \pm .07$. For the sub-series B pairs, the correlation was $+.80 \pm .07$. The high reliable correlations between the rank order of equivalence ratings for each sub-series when presented in two different orders show that order of presentation had no effect on the distribution of equivalence choices.

Taken together, the evidence from number of equivalent pairs chosen and

TABLE 2
Effect of order of presentation on average number of equivalent pairs chosen

Pairs	Mean Number of Equivalent Pairs		Mean Difference	t	Degrees of Freedom	Probability of Occurrence by Chance
	Order of Presentation					
	1st	2nd				
Sub-series A	3.9 N=39	3.5 N=38	0.4	0.666	>30	50%
Sub-series B	5.7 N=38	5.9 N=39	-0.2	0.222	>30	82%

bution of choices of the equivalent pairs. For this purpose, the equivalence ratings of sub-series A pairs, and of sub-series B pairs were calculated separately (as described on p. 10) under the two conditions: when a particular sub-series was presented first; and when it was presented second. The rank order of equivalence ratings of the sub-series A pairs when presented first was correlated with the rank order of equivalence ratings of sub-series A pairs when presented second. The same was done for the sub-series B pairs. In both cases all animals on all tests were divided on the basis of whether they had the same order of presentation.

from equivalence ratings shows that order of presentation does not affect the number or distribution of equivalence choices; and therefore data from these sub-groups may be combined in making further comparisons.⁷

Thus it has been found that variation in training technique does not affect the nature or the stability of the original learning, and that variation in the order of presentation of the critical series has no effect upon the number or distribution of the equivalence choices, i.e., no observable differences resulted from variation of either of two different situational factors.

⁶ See footnote 2, p. 14.

⁷ See footnote 5, p. 15.

II. EFFECT OF OPERATION AND RETESTING ON EQUIVALENCE REACTIONS

Whereas the previous section showed that variation in the situational factors failed to produce any observable effect on equivalence reactions, the present section will show that variation of factors *within the individual* are effective in altering equivalence reactions. The first variable investigated was the effect of cortical injury.⁸ A second factor investigated was the effect of repeated experience with the critical series, i.e., retesting.

Comparisons of the three main groups were utilized for study of these factors. As reference to the section on procedure will show, the three major groups were: I. Normal (Test—vacation—retest); II. Post-operated (Test—operation—retest); and III. Pre-operated (Operation—test). Considering first the Normal Group, any difference found as to performance on the first and second test would show the effect of retesting alone, i.e., any change observed could be assigned to the previous experience. Considering next the Post-operated Group, any difference found between the first test, prior to operation, and the second test, following

operation, would show dual effects of operation together with retesting. In addition to these intra-group comparisons, inter-group comparisons or cross-comparisons between groups can be made as follows. The first test of the pre-operated animals may be compared with the first test of normal animals (Normal and Post-operated Groups) to show the effect of operation directly; the effect of operation is also shown, but in a different way, by comparing the second test of the Post-operated Group with the second test of the Normal Group. The comparisons which give the effect of retesting alone can be taken as a reference point in evaluating the results from the operated groups.

In order to evaluate the behavioral effects of operation and retesting the results were examined according to a variety of criteria. The criteria used were: (1) number of equivalent pairs, (2) percentage of animals regarding each pair as equivalent, and (3) equivalence rank order. The data in terms of these criteria are based on results found in the master Tables 3, 4, and 5, and the criteria will serve as convenient headings for presenting the operation and retesting data.

A. Number of Equivalent Pairs

Data for comparison by this criterion were obtained by finding the number of equivalent pairs for each animal, and computing the average number of equivalent pairs for each major group on each test occasion. The results are given in Table 6 under the heading "all pairs."

While the normal animals chose an average of 8.7 equivalent pairs on their first test, they choose only 8.8 equivalent pairs on retest. It is clear that retesting alone does not affect the number of

⁸ It is worthy of note that the original learning was impaired after operation, for the animals that suffered cortical injury (Post-operated Group) generally took more trials to relearn the original discrimination than the normal animals (Normal Group). No data are presented to substantiate this point because in the first place the major concern of this paper was with the equivalence reactions, and secondly, because one of the secondary purposes was to determine the effect of a situational factor (learning technique) on equivalence reactions. Since errors and trials had one meaning in the single-jump technique and another in the multiple-jump technique, it was not legitimate to group together rats which had similar error scores if they learned by different techniques. Separate treatment of the results for the two techniques results in an inadequate sample, which does not admit of statistical analysis, and hence these limited results were omitted.

TABLE 3
Equivalent pairs for normal group

Rat	Number Equivalent Pairs	Pairs Found Equivalent																			
		First Test																			
X82F	16	I	2	3	4	5	6	7	8	9	10	11	12	12	16	18	20	21	23		
103F	16	I	2	3	4	5	(6)	7	8	9	10	11	12	12	16	18	20		23		
X05F	16	I	2	3	4	5	6	7	8	9	10	11	12	13	16	18	20				
X86F	15	I	2	3	4	5	6	7	8	9	10	11	12	13	16	18	20				
X82M	14	I	2	3	4	5	6	7	8	9	10	11	12	13	15	18	19				
X63F	14	I	2	3	4	5	6	7	8	9	10	11	12	13	15	17	20	21			
78F	11	I	2	3	4	5	6	7	7	9	10	11	12	13	15	(17)	19		22		
X76F	9	I	2	3	4	5	6	7		9			12	15							
360M	6	I	2	3	4	5			9												
X67M	5	I	2	3	4		6		(8)							(17)					
300F	3	I	(2)			5	6														
X83M	3	I																			
X85F	2	I																			
171M	1	I																			
355F	0																				
Av.		8.7																			
Per cent		80	67	67	60	60	53	53	47	53	47	47	33	27	20	20	13	20	13	7	13
Second Test																					
X82F	7	I	2	3	4	5		7	8	9	10	11	12	(13)	15	19					
103F	11	I	2	3	4	4	5	7	8	9	10	11	12	13	14	15	18	21			
X85F	14	I	2	3	4	4	5	7	8	9	10	11	12	13	14	15	17				
X86F	15	I	(2)	3	4	5	5	7	8	9	10	11	12	13	14	15	17			23	
X82M	16	I	2	3	4	5	5	7	8	9	10	11	12	13	14	15	17				
X63F	15	I	2	3	4	5	5	7	8	9	10	11	12	13	14	15	17	18			
X87F	14	I	2	3	4	5	5	7	8	9	10	11	12	13	14	15	17				
X76F	16	I	2	3	4	5	6			9	10	11	12	13	15	16	20		22	23	
360M	13	I	2	3	4	5		7	8	9	10	11	(12)	13	15	16					
X87M	14	I	2	3	4	5		7	8	9		11	(12)	14	15	(16)					
300F	5	I			4	5			8				14	15							
X88M	0																				
X87F	0	I																			
171M	0	I																			
355F	1	I				5															
Av.		8.8																			
Per cent		60	53	60	60	53	7	60	60	47	47	60	33	53	53	47	40	33	13	7	13
Per cent Difference		-20	-14	-7	0	-7	-46	+7	+13	-6	0	+13	0	+26	+33	+27	+13	+13	-7	-6	0

TABLE 4
Equivalent pairs for post-operated group

Rat	Number Equivalent Pairs	Pairs Found Equivalent																						
		First Test										Second Test (After Operation)												
X83M	17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	(22)	
356M	17	1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	(18)	19	20	21	
172M	16	1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
359M	14	1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
X74F	14	1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
357F	11	1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
X81M	9	1	2	2	3	4	5	6	7	8	(9)	10	11	12	13	14	15	16	17	18	19	20	21	
357M	7	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
X07F	7	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
X59M	3	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
358M	2	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
355M	2	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
X56F	1	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
70F	0	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
X78M	0	1	2	2	3	4	5	6	7	8		10	11	12	13	14	15	16	17	18	19	20	21	
Av.	8.0																							
Per cent		87	67	47	53	53	47	40	47	27	33	33	33	27	33	33	20	27	20	13	20	13	0	
X83M	17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
356M	17	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
172M	9	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
X77F	10	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
357F	11	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
X81M	11	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
357M	17	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	(16)	17	18	19	20	21	22	
X50M	14	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	(16)	17	18	19	20	21	22	
358M	1	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	(16)	17	18	19	20	21	22	
355M	1	1	2	3	4	5	(6)	7	8	9	10	11	12	13	14	15	(16)	17	18	19	20	21	22	
X56F	18	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
70F	17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
X78M	17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Av.	11.0																							
Per cent		80	67	67	80	53	40	75	75	60	67	80	20	75	60	53	67	33	40	13	27	33	7	20
Per cent Difference		-7	0	+20	+27	0	-7	+33	+26	+33	+34	+17	-13	+46	+27	+20	+47	+6	+20	-14	+14	+13	-0	+20

equivalent pairs chosen. Such a conclusion is further supported by the fact that 6 animals showed a decrease in the number of equivalent pairs chosen, 7 showed an increase, and 2 showed the same score on the second test as on the first test.

In the same manner, the scores of the Post-operated Group may be examined to demonstrate the effect of an operation

greater weight as evidence than differences obtained from independent samples, i.e., differences obtained from inter-group comparisons. Secondly, the equivalence scores themselves are based upon either 6 or 12 presentations of each critical pair, and the judgment as to whether a particular pair is equivalent is made by taking chance effects into account. For this reason a student's *t* score which

TABLE 6
The effect of operation and retesting on the number of equivalent pairs chosen

Group	Test	N	Mean Number of Equivalent Pairs		Mean Difference		t		Degrees of Freedom	Probability of Occurrence by Chance	
			All Pairs	Critical Pairs	All Pairs	Critical Pairs	All Pairs	Critical Pairs		All Pairs	Critical Pairs
Normal	1	15	8.7	6.2	0.1	0.5	0.087	0.610	14	90%	55%
	2	15	8.8	6.7							
Post-Operated	1	15	8.0	5.1	3.9	4.3	2.191	3.333	14	5%	<1%
	2	15	11.9	9.4							
Normal (I and II) Pre-Operated	1	30	8.3	5.7	1.6	1.4	0.851	1.000	45	40%	30%
	1	17	9.9	7.1							
Normal Post-Operated	2	15	8.8	6.7	3.1	2.4	1.314	1.333	28	20%	20%
	2	15	11.9	9.1							

intervening between the first and second test occasion, since it has just been shown that retesting would not be a complicating factor. The Post-operated Group had a mean score of 8.0 equivalent pairs for the first test, but after operation had a mean score of 11.9 equivalent pairs. This increase of 3.9 pairs (48.8 per cent) is probably significant (see Table 6).

In all discussions of statistical significance or non-significance of differences obtained throughout this paper, the following observations must be kept in mind. In the first place, since there is so much individual variation in equivalence scores, the means of *related* measures, i.e., differences obtained from intra-group comparisons, should be given

occurs 2 per cent or less than 2 per cent of the time by chance is regarded as significant; differences which occur from 2 to 5 per cent of the time by chance are regarded as of "probable" significance; and differences which occur more than 5 per cent of the time by chance are regarded as not significant. The values for "probable" significance are not given weight in drawing a conclusion, unless there is supporting evidence from other sources.

Analysis in terms of the number of animals showing an increase, decrease, or the same score after operation further supports the inference that operation results in an increase in the number of equivalent pairs chosen. Four animals

show slight decreases in the number of equivalent pairs chosen on the post-operative test, 2 show the same score, and 9 show an increase in the number of equivalent pairs chosen.

Further, inter-group comparisons show a trend which is compatible with the idea that operation tends to increase the number of equivalent pairs, although none of the differences are statistically significant. For example, as indicated in Table 6, the average number of equivalent pairs is 1.6 pairs higher for the Pre-operated Group than the average number of equivalent pairs for the Normal Group when the first tests of both groups are considered. On the second test the Post-operated Group chose on the average 3.1 more pairs as equivalent than the Normal Group. In other words, inter-group comparisons likewise show that there is a negligible effect of retesting whereas there is a considerable change following operation.

If one regards the entire critical series as analagous to a test, then it is logical to assume that certain of the items (pairs) of the test may be more critical than others in the sense that the latter do not discriminate between the effects of operation and retesting. In an item analysis of any test, after it has been administered to a standard group, each item is evaluated to see how well it discriminates among individuals who differ according to some independent criterion of ability, such as the total score on the test. In making up the final test, only the items which discriminate are retained. Applying this to the critical series, it was found that certain of the pairs were not "good" in the sense that they did not discriminate between the major groups in the same way that the total test did. If one arbitrarily sets up a criterion of the discriminating ability which a pair must have in

order to be retained in the test, then it is possible to rework the number of equivalent pair analysis in terms of the discriminating or "crucial" pairs. A pair was considered discriminating if it showed a 20 per cent change or greater for either the Normal Group or the Post-operated Group on the first as compared to the second test. With this criterion in mind, examination of Tables 3 and 4 shows that pairs 1, 3, 4, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, and 18 are the crucial pairs.

Considering only these crucial pairs, the effect of operation and retesting was evaluated in the same way as for the *total* number of equivalent pairs. Examination of the comparisons of the major groups in Table 6 (under crucial pairs) shows that when only the "crucial" pairs are considered, the effect of operation upon the number of equivalent pairs chosen becomes more pronounced. For example, the difference in the mean number of crucial equivalent pairs before and after operation for the Post-operated Group is highly significant, for a difference of this size could occur less than 1 per cent of the time by chance.

Thus according to the criterion number of equivalent pairs, there are indications from intra-group and inter-group comparisons of all critical pairs and crucial critical pairs that retesting has little effect on equivalence reactions whereas operation produces alterations in equivalence reactions.

B. Percentage of Animals Regarding Each Pair as Equivalent

Data for comparison by the second criterion were obtained by computing the percentage of animals that regarded each of the 23 critical pairs as equivalent on the first test. A separate calculation was made using the results of the second test. Then the mean percentages for the two

tests were compared. This procedure was carried out for both the Normal Group and the Post-operated Group, and the results are given in Table 7. It will be seen that the mean percentage increase for normal animals was 0.6 per cent, which is not significant. This result supports the analysis made above, since it indicates that retesting had little influence on the equivalence reactions.

For the Post-operated Group, on the other hand, the mean percentage in-

relating the equivalence rank orders obtained from the appropriate groups. A high positive correlation would show that the equivalence reactions have been distributed among the critical pairs in essentially the same way despite the difference in conditions. If the order of distribution were altered, one might expect a low positive, zero, or negative correlation.

The first comparison was made between the first test of the Normal Group

TABLE 7

The percentage of animals reacting to each pair as equivalent on first and second test

Group	Test	N (Pairs)	Mean Per Cent Animals Reacting to Pairs as Equivalent	Mean Differ- ence	t	Degrees of Freedom	Probability of Occurrence by Chance
Normal	1	23	37.7	0.6	0.095	44	>90%
	2	23	38.3				
Post-operated	1	23	34.8	16.8	2.679	44	<1%
	2	23	51.6				

crease from first to second test is 16.8 per cent, which is significant. These data provide further evidence for the inference that operation tends to increase the number of equivalence reactions.

The data from the second criterion, percentage of animals regarding each pair as equivalent, show the same trend as those from the first criterion, in that retesting has no effect, whereas operation produces a significant change in equivalence behavior.

C. Equivalence Rank Order

The third criterion, equivalence rank order, which has been used before (p. 14) to study the effect of training technique on distribution of equivalence choices, can be used here to study the effect of operation and retesting on distribution of equivalence choices, by cor-

relating the equivalence rank orders obtained from the appropriate groups. A high positive correlation would show that the equivalence reactions have been distributed among the critical pairs in essentially the same way despite the difference in conditions. If the order of distribution were altered, one might expect a low positive, zero, or negative correlation.

The equivalence rank order of the Normal Group on the first test was then correlated with the equivalence rank order of the Normal Group on its second test, which would show the redistribution due to retesting when compared with the previous correlation. The correlation in this case, $+0.71 \pm 0.07$, was slightly lower than that found for the two samples of normal animals. This suggests that there may be a slight alteration in equivalence rank order of the critical pairs as a result of retesting.

The equivalence rank order of the

Post-operated Group on the first test was correlated with the equivalence rank order of the Post-operated on the second test, which followed operation. The correlation was $+.63 \pm .09$, which when compared to the first correlation (two samples of normal animals) shows that there was some tendency for change in equivalence rank order following operation.

Although the exact nature of the change in each of these cases is not indicated by these data, later discussion of relational responses will indicate factors which might account for the change.

Thus the equivalence reactions according to the first two criteria considered, number of equivalent pairs, and percentage of animals choosing each pair as equivalent, are not affected by retesting, but do show definite effects following operation. The results by the third criterion, equivalence rank order, suggest that both operation and retesting may have some effect on the distribution of equivalence choices.

III. DETAILED ANALYSIS OF EQUIVALENCE REACTIONS

It has been shown in the preceding discussion that operation is the dominant factor producing significant alterations in equivalence behavior, although retesting may have some slight effects. The next logical step is to see whether the data offer any evidence concerning the nature of these changes. First the data were analyzed to determine the effect of operation and retesting on responses made in relational terms. A second analysis was made to determine what aspects of the original training pair provided the basis for the original discrimination.

A. Relational Responses

Since certain cards occurred in more

than one critical pair, there is a possibility that a rat which chooses both pairs as equivalent may make a positive response to the common card when it occurred in one pair and a negative response to the same card when it occurred in the other pair. When this occurred, it was taken as evidence that the rat was responding to a relationship. An example will clarify the method employed to identify relational responses. The card with a large gray circle on a black background (Plate 1) occurs as a member of pairs 3, 4, 13, 14, and 20. This constitutes one relational set. Two conditions would have to be met before giving an animal credit for a relational response. First, two or more of the pairs in this set would have to be chosen as equivalent on the same test; second, the card common to both pairs would have to be avoided in at least one case, and preferred in at least one case. For example, if pairs 3, 13 and 20 were equivalent for a particular animal, and the large gray circle were avoided in pair 20 and preferred in pairs 3, and 13, the animal would be given a score of one relational response.

Since the main point of interest is that the rat prefers this card in one type of situation and avoids it in other types, the ratio of preference to avoidance is considered relatively unimportant and therefore no more than one relational response can be scored for each individual set. Either a rat shows a relational response (reversal in reaction to the common card) within each set or he does not. There were ten such sets in all:

1. Large gray on black ground: 3, 4, 13,
14, 20
2. Medium gray on black ground: 2, 8,
10, 21
3. Large white on black ground: 9, 18
4. Medium white on black ground: 11,
16, 21

5. Large white on gray ground: 7, 17, 19
6. Medium white on gray ground: 6, 10
7. Small white on gray ground: 1, 12, 13, 18, 19
8. Medium black on gray ground: 6, 8, 14
9. Medium gray on white ground: 2, 23
10. Medium black on white ground: 11, 23

To determine the effects of operation and retesting the mean number of relational responses was compared for each of the major groups on each test occasion.

called that the section on equivalence rank order also showed a slight tendency for operation to result in a redistribution of choices. The comparisons of relational responses for the Post-operated Group indicate that the redistribution of choices due to operation functions in the opposite direction from the redistribution due to retesting.

Inter-group comparisons further support the conclusion that operation results in a greater number of relational re-

TABLE 8
The effect of operation and retesting on the number of relational responses

Group	Test	N	Mean Number of Relational Responses	Mean Difference	t	Degrees of Freedom	Probability of Occurrence by Chance
Normal	1	15	1.00	-0.33	1.031	14	31%
	2	15	.67				
Post-operated	1	15	1.20	1.07	2.277	14	4%
	2	15	2.27				
Normal (I and II) Pre-operated	1	30	1.10	0.31	0.738	45	47%
	1	17	1.41				
Normal Post-operated	2	15	.67	1.60	3.200	28	<1%
	2	15	2.27				

sion. These comparisons, given in Table 8, show that for the Normal Group there is an insignificant reduction, .33 (33 per cent) in relational responses on the second test compared to the first test. It is worthy of note that the slight redistribution of choices indicated by the equivalence rank order data for the Normal Group on these same tests discussed in the previous section might be related to the slight reduction in the number of relational responses.

In contrast to the data for the Normal Group, there is a marked increase of 1.07 (89.1 per cent) relational responses for the Post-operated Group on the second compared to the first test. This increase is probably significant and indicates that operation leads to more relational responses. Again it will be re-

sponses. The Post-operated Group on its second test shows 1.60 more relational responses than the Normal Group on its second test, a difference which is highly significant. The first test of the Pre-operated Group shows a difference in the same direction, although the difference is not significant.

These data indicate that retesting results in an insignificant reduction whereas operation results in a significant increase in the mean number of relational responses made.

B. Consistency of Preference

Since the judgment of equivalence or non-equivalence of a pair depends upon the consistent preference which individual animals show for one of the two members, it is pertinent to ask how con-

sistent the animals in each group were in making a positive response to a *particular member* of a pair of critical cards, whenever the pair was regarded as equivalent.

In Plate 1, the card preferred by the majority of the animals is placed on the left under +; and in Tables 3, 4, and 5, reversed preferences are indicated by parentheses. Analysis reveals that the individual animals showed a striking consistency as to the preferred member of a particular equivalent pair. The normal animals (Normal and Post-operated Group) on their first test made a total of 250 equivalence choices, only 8 (3.2 per cent) of which were inconsistent with the preference of the majority. For the animals tested after operation (Post-operated Group—second test) only 5 (2.8 per cent) inconsistent responses were made out of a total of 178 equivalence reactions. In the Pre-operated Group, out of a total of 168 equivalence reactions, only 5 (3.0 per cent) preferences were inconsistent with the majority of the group. A comparable uniformity of preference was shown in the Normal Group on its second test, for out of a total of 132 equivalence choices, only 4 (3.0 per cent) preferences were inconsistent with the majority of the group.

The fact is clear that whenever the members of a group of animals choose the same critical pair as equivalent, there is a strong tendency for them to react positively to the same card. Furthermore, Maier (43) has shown that the preference for a particular member of a critical pair is a product of the training. Using the same training pair that was used in this experiment, half of the animals were trained to react positively to the card containing the large black figure, and half were trained to react positively to the card containing the small black

figure. He found that the animals of these two groups showed opposite preferences, in the sense that the animals of one group preferred one member of a critical pair, and the animals of the other group preferred the other member of the critical pair. Reversal of training, therefore, resulted in reversal of the preferences. For the animals of the present investigation, not only is there consistent preference within each group, but the animals of all groups show the same preference when they chose a particular pair as equivalent. Thus the differences between the major groups, if there are such differences, cannot be described in terms of reversed preferences, but rather must be described in terms of percentage preferences. First a gross analysis will be made to determine the basis of the preferences, and then analysis of the percentages will be made to reveal any possible differences in preference between the major groups.

C. Basis for Learning

The striking consistency in preference just demonstrated must rest on the fact that equivalence choices are made according to some definite property or group of properties which the critical pairs have in common with the training pair; or at least, this is the basic assumption behind all equivalence experiments. But, nevertheless, it appears that even for the rats, the critical pairs are not identical with the training pair, because they hesitate and "look over" both cards when first confronted with the critical pairs.

Within the limits of the experiment it is possible, owing to the way the critical pairs were constructed, to analyze the equivalence choices with the object of finding what properties form the basis for the equivalence reactions. The an-

alysis will be made in terms of the combinations of equivalent pairs chosen by the different animals, and in terms of the preferred cards of the equivalent pairs.

It will be recalled that the original discrimination involved at least two important differences. The first was the size difference in the figures, the positive card having the larger figure. The second was the difference in the total amount of light reflected,⁹ the positive card being darker. It has been mentioned that the critical pairs were designed at the time the experiment was planned to study the importance of the two factors, size and brightness. This was accomplished by having both factors work in the same direction in some pairs, and having them work in opposition in other pairs. For instance, in one pair both size and brightness would favor the choice of the same card, in the sense that they both corresponded to the properties of the positive card of the training pair, i.e., the card having the larger figure was also totally darker. In other pairs, the size difference favored one card of the pair while the brightness difference favored the other card, i.e., the card having the larger figure would be totally brighter whereas the card having the smaller figure would be darker. In certain pairs the factors would be equated.

If the size difference were the only important aspect for some particular animal, one might expect that animal to choose as equivalent only those critical pairs where there was a difference in the size of the figures. In some of the pairs,

⁹ Since combinations of white, black, and intermediate gray were used in designing the cards, the total amount of light reflected could be calculated and expressed in relative terms for the cards of a pair. This was done by computing the area of black, gray, and white in each of the cards making up a pair. For convenience this property will hereafter be referred to as a brightness difference.

both figures were the same size, and on these a "size animal" should make chance scores. The critical pairs which one might expect a "size animal" to choose as equivalent are: 1, 3, 4, 5, 7, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22. An examination of Tables 3, 4, and 5 (the equivalent pairs chosen) shows that no animal chose this combination of critical pairs as equivalent. Only one animal, which chose 3 or more equivalent pairs, X₁₃₄M (Pre-operated Group) limited its equivalence choices to pairs within this "size" group.

More convincing evidence against the hypothesis that any of the animals might have learned the discrimination purely in terms of size may be found on examining the preferred member of the equivalent pairs. Reference to Plate 1, will show that for this series of 16 cards having a size difference, i.e., the pairs mentioned above, the card having the larger figure was preferred by the great majority of animals in 12 pairs, i.e., in 75 per cent of the pairs. Superficially this seems to show that the animals make considerable use of the size difference during learning. When interpreting the results, however, the effect of the other factor, brightness, must be taken into account. In all 12 pairs where the animals appeared to choose according to size, brightness either favored the same card, or was equated for both cards. The most conclusive evidence that brightness is a dominant factor is derived from a consideration of the pairs where the brightness factor opposed the size, pairs 7, 14, 16, 19, and 20. The preferences indicate that brightness was clearly more important than size, since in 4 out of these 5 pairs, the preference was for the darker card rather than the one having the larger figure.

If the total brightness difference were the only important aspect for an animal, one might expect that animal to choose as equivalent only those critical pairs where there is a difference in the total amount of light reflected from the two cards. In some pairs, both cards have the same brightness, and on these a "brightness animal" should make chance scores. The critical pairs which one might expect a "brightness animal" to choose as equivalent are :1, 2, 3, 4, 6, 7, 9, 10, 11, 13, 14, 16, 19, 21, and 23. An examination of Tables 3, 4, and 5 shows that no animal chose this combination of critical pairs as equivalent. There were 3 rats having more than 3 equivalent pairs that limited their choices to pairs within this brightness group. They were X87M (Normal Group, first test), 75M (Pre-operated Group, first test), and 172M (Post-operated Group, second test). The larger number of animals limiting their equivalence choices to pairs within this group than within the "size" group is a slight indication that brightness is more effective than size.

Confirming evidence will be found on reference to Plate 1, which shows that for this series of 16 pairs mentioned above, which could be discriminated in terms of total brightness, the darker card was preferred by the great majority of the animals in 15 out of the 16 pairs, or 94 per cent of the pairs. This suggests that the animals make considerable use of the brightness difference in learning. Furthermore, for the only pairs where the brightness factor opposed the size, pairs 7, 14, 16, 19 and 20, as indicated above, the preferences indicate that brightness was more important because the animals choose the darker card in preference to the card having the larger figure, in all but pair 14. This pair, however, does not show as great a brightness

difference as any of the other pairs; and further, the card avoided has many features which resemble the absolute properties of the negative card of the training pair. The data definitely support the conclusion that brightness is the dominant factor.

The case for the animal's choosing on the basis of the total brightness difference is strong, but one must also consider that when no brightness difference exists, the animals are able to utilize size differences. For example, in pairs 5, 15, and 22 which had no total brightness difference, the animals chose the card containing the larger figure. We may infer that the animals utilized a *combination* of at least two properties on occasion, size and brightness difference. Now it is proper to ask which of these two aspects of the training pair is more important to the animal in making its equivalence choices.

It will be noted that in designing the cards to fulfill the desired conditions, another variable was necessarily introduced, namely, reversal in figure-ground relations. In the original discrimination, both positive and negative cards had dark figures on lighter grounds. Since both cards of the training pair show the same figure-ground relations, it was not possible for the rats to learn the original discrimination purely in terms of this property. It would sometimes occur in the critical series that one card would have the figure-ground relations found in the training pair, and the other card have the reversed figure-ground relations. By a card having a reversal of figure-ground relations is meant one which had a light figure on a darker ground. Then it might turn out that the rat would prefer the original relations of the figure to the ground rather than the new relations, in making equivalence

choices. That is, the reversal might prove a disrupting influence, and in that way the figure-ground factor might influence the preferences. Thus in evaluating the importance of any single factor, each must be considered in relation to two others; so that in all, three factors must be taken into account: figure-ground relations, size, and brightness.

The exact situation with regard to factors favoring or opposing a preference for each individual pair can be represented in symbolic form by a schema given in Table 9. S represents size, B represents total amount of light reflected, and F represents the figure-ground relations.

TABLE 9
Symbolic representation of the critical pairs

Case	Symbolic Representation*	Pairs
1	SBF vs. $\overline{\text{SBF}}$	1
2	SBF vs. $\overline{\text{SBF}}$	3, 4, 9
3	$\overline{\text{SBF}}$ vs. SBF	16
4	SBF vs. $\overline{\text{SBF}}$	14
5	$\$ \text{BF}$ vs. $\$ \overline{\text{BF}}$	2, 11
6	$\$ \text{BF}$ vs. $\$ \overline{\text{BF}}$	6
7	$\$ \overline{\text{BF}}$ vs. $\$ \text{BF}$	12
8	SBF vs. $\overline{\text{SBF}}$	17
9	$\overline{\text{SBF}}$ vs. SBF	13
10	SBF vs. $\overline{\text{SBF}}$	7, 19, 20
11	$\$ \overline{\text{BF}}$ vs. $\$ \text{BF}$	5, 15, 18, 22
12	$\$ \text{BF}$ vs. $\$ \overline{\text{BF}}$	10, 21, 23
13	$\$ \overline{\text{BF}}$ vs. $\$ \text{BF}$	8

* The combinations chosen by the majority of the animals are on the left, i.e., the preferred card is on the left. The symbolic representation of each pair is based upon the calculations (discussed in note 9 on p. 27) of the relationships between the physical aspects of the critical pairs, which were made at the time the experiment was planned. See text for the meaning of the symbols.

Three letters, representing the 3 factors, are given for each card of a pair. Where the capital letter only appears, the factor favors preference for that card, in the sense that this feature corresponds to the same factor found in the positive card of the training pair. Thus S means

that the card in question has a larger figure. Where the capital-bar ($\overline{\text{S}}$) appears, the factor in question works against the preference for that card. Thus $\overline{\text{S}}$ is applied to a card having the smaller figure. If one card is S, the other card of a pair must be $\overline{\text{S}}$. If the factor in question is equated (instead of being opposed) for the two cards of a pair a different symbolism is employed, namely, both appear as capital-cancelled ($\$$). For example, a card symbolized by SBF would be one where size favored preference for the card, while brightness and figure-ground both worked against preference for the card. It would necessarily be paired with a card symbolized by $\overline{\text{SBF}}$. A card symbolized by $\$ \text{BF}$ would be one where size favored preference for the card, where brightness was equated, while figure-ground relations worked against preference for the card. Such a card would necessarily be paired with a card symbolized by $\$ \overline{\text{BF}}$.

One or more pairs were constructed to represent each of the possible combinations. Therefore, all the pairs of the critical series can be represented by one of the sets of symbols given in the schema in Table 9. Since the preferences of the animals are indicated in the table (the combinations chosen by the majority of the animals are on the left), it is possible to analyze these preferences in terms of the aspects studied.

By examining the schema, one can isolate cases involving figure-ground relations, working with and against the other factors in a variety of combinations. Case 1 shows that where the brightness and size and figure-ground relations all favor the choice of the same card (in the sense of being like the original positive card), all of the animals prefer this card whenever the pair is chosen as equivalent. From case 2 it will

be seen that where figure-ground favors one card, while size and brightness together favor the other, the rat prefers the card favored by size and brightness, i.e., figure-ground does not have a strong enough influence to overcome the combined brightness and size cues. Case 3 shows that where figure-ground and size work together against brightness, the animals nevertheless choose according to brightness. Case 4 shows that where figure-ground and brightness work together against size, the animals choose according to size. In case 6, where size is equated and brightness and figure-ground favor the same card, the animals choose this card. In case 7, where brightness is equated and figure-ground and size favor the same card, the animals choose this card. Case 5, however, shows that where size is equated and brightness is opposed to figure-ground, the animals choose according to brightness. Case 8 shows that where brightness is equated and size is opposed to figure-ground, the animals choose according to size. Thus we can see that no matter what factor or combination of factors may be set in opposition to figure-ground, the figure-ground relations are ineffective in determining the preferences.

Case 13 shows the effect of figure-ground when it is the only cue available (both size and brightness are nearly equated physically). The animal avoids the card which shows the same figure-ground relationship as the training pair. But there is only one pair that represents this case, and the card which is avoided here is the same one avoided in previous case 4. As has already been suggested this card may have been avoided because it resembles the negative card of the training pair.

Having shown that the figure-ground factor is, in itself, a negligible influence

in determining preference, it is legitimate to group together cases which differ in respect to the figure-ground factor only, when examining the preferences with respect to size and brightness. Where size and brightness favor the same card, cases 1, 2, and 9, all of the animals favor this card, whenever the pairs falling under these cases are chosen as equivalent. Where brightness is physically equated, cases 7, 8, and 11, the majority of the animals choose the card having the larger figure, i.e., choose according to size. Where size is physically equated, cases 5, 6, and 12, the majority of the animals choose the darker card, i.e., according to brightness. When size favors one card and brightness favors the other card, cases 3, 4, and 10, the majority of the animals choose the darker card, i.e., choose according to brightness in 4 out of the 5 pairs which represent these cases. The exception, pair 4, has already been accounted for.

These data suggest that the most important factor in determining the animal's choice is the brightness factor. The animals for the most part will choose on the basis of size if it is the only cue available; or if the brightness and size work in the same direction they will choose the card favored by both factors. If brightness is opposed to size, however, the brightness factor determines the animal's preferences, i.e., the darker card rather than the card with the larger figure is preferred. In other words, if the animal is confronted with a critical pair having one card darker than the other, it may be predicted that if the pair is reacted to as equivalent, the animal will prefer the darker card, regardless of the size relations involved, when trained on the discrimination used in this experiment.

There is another way of evaluating

the importance of brightness, size, and figure-ground preferences, utilizing the symbolic representation given above (Table 9). Taking any one of the three factors, there were a certain number of critical pairs which differed in respect to the factors selected. Knowing this, it is possible to find the ratio of the number of times a preference in terms of a given

larger figure was chosen out of the total number of opportunities to express such a preference was calculated. And finally the same procedure was carried out for the figure-ground choices, i.e., for the equivalent pairs, the percentage of choices in terms of the figure-ground relations in the same direction as the training pair was calculated out of the total

TABLE 10
Comparison of size, brightness, and figure-ground choices

Group	Test	N	Percentage Preference		Mean Difference	t	Degrees of Freedom	Probability of Occurrence by Chance
			Brightness	Figure-ground				
Normal (I and II)	1	30	86.8	42.8	44.0	6.937	29	<1%
Pre-operated	1	17	93.9	43.9	50.0	5.682	16	<1%
Normal	2	15	69.1	21.5	47.6	4.750	14	<1%
Post-operated	2	15	92.6	33.1	59.5	7.169	14	<1%

			Size	Figure-ground				
Normal (I and II)	1	30	74.8	42.8	32.0	5.424	29	<1%
Pre-operated	1	17	80.5	43.9	36.6	5.304	16	<1%
Normal	2	15	73.6	21.5	52.1	6.277	14	<1%
Post-operated	2	15	83.2	33.1	50.1	6.185	14	<1%

			Brightness	Size				
Normal (I and II)	1	30	86.8	74.8	12.0	4.444	29	<1%
Pre-operated	1	17	93.9	80.5	13.4	2.094	16	5%
Normal	2	15	69.1	73.6	-4.5	0.511	14	51%
Post-operated	2	15	92.6	83.2	9.4	2.293	14	4%

factor was actually expressed to the total number of opportunities to express preference in terms of the particular factor. Since the total number of opportunities to express a preference is not the same for all three factors, the comparisons must be made in percentage terms. The percentage of equivalence choices where the animal preferred the darker card out of the total number of opportunities to express such a preference was calculated. The same procedure was carried out for the size choices, i.e., considering only the pairs chosen as equivalent, the percentage of times the

number of opportunities to express such a preference.

In summary, taking into account the number of preferences expressed on the equivalent pairs only, the values compared were calculated as follows for each animal:

$$\begin{aligned} \text{Percentage brightness preference} &= B/(B + \bar{B}) \times 100 \\ \text{Percentage size preference} &= S/(S + \bar{S}) \times 100 \\ \text{Percentage figure-ground preference} &= F/(F + \bar{F}) \times 100 \end{aligned}$$

The values are given separately for each group on each test occasion in Table 10.

One can then evaluate the relative

importance of the three factors in determining the animal's preference by comparing these percentages. First, the importance of the brightness factor will be compared with the importance of the figure-ground factor, then the importance of the size factor will be compared with the importance of the figure-ground factor, and finally the brightness factor will be compared with the size factor.

Table 10 (part 1) shows that all groups on all test occasions make a higher percentage of preferences to a darker card than they do to a card which has its figure-ground relations in the same direction as the original training pair, i.e., brightness has a greater influence on the preferences than figure-ground relations. In all these cases the differences are highly significant.

Furthermore, part 2 of Table 10 reveals that all groups on each test make a higher percentage of preferences to a card containing a larger figure than they do to a card which has its figure-ground relations in the same direction as the original training pair, i.e., size is much more likely to influence preferences than figure-ground relations. In all cases these differences are highly significant.

These data substantiate the findings noted in the gross preference analysis that changing the figure-ground relations has little effect on equivalence preferences and is less important in determining these preferences than either brightness or size of the figure of the card.

A similar analysis is made in part 3 of Table 10 with respect to the importance of size and brightness in determining the preferences. The normal animals (Normal Group and Post-operated Group) on their first test made 86.8 per cent of their brightness preferences to the darker card

of a pair, whereas they make only 74.8 per cent of their size responses to the cards containing the larger figure. The mean difference 12.0 is highly significant. The Pre-operated Group shows the same trend. On their first test they make 93.9 per cent of their brightness responses to the totally darker card, and 80.5 per cent of their size responses to the card having the larger figure. The mean difference 13.4 per cent, is probably significant. The second test of the Post-operated Group shows the same trend. They make 92.6 per cent of their brightness choices to the darker card, but only 83.2 per cent of their size choices to the card having the larger figure. The mean difference, 9.4 per cent, is probably significant. The only difference in trend comes for the second test of the Normal Group. They make only 69.1 per cent of their brightness choices to the darker card, and 73.6 per cent of their size choices to the card having the larger figure. Although this difference of 4.5 per cent is in the opposite direction from that found in the other groups, i.e., in favor of the importance of size, the difference is not significant.

In summary, it is evident that shifting the figure-ground relations has little effect on the animal's preferences. Size and brightness are significantly more important than maintenance of the original figure-ground relations. But the most important aspect in determining the animal's preferences is brightness, except in the case of retesting normal animals, where the size aspect is just as important as brightness.

D. The Effect of Operation and Retesting on Size and Brightness Choices

The next detailed analysis was designed to show the effect of operation

and retesting on the size and brightness preferences. The figures already given above indicate that retesting may differ in effect from operation because of the difference in trend observed for the second test of the Normal Group, i.e., the greater percentage of size than brightness choices.

general tendency of the group with respect to the variable tested, and the variance test should give some information as to whether the samples were drawn from equally variable populations, i.e., whether there are changes in individual differences with respect to the variables tested or whether the

TABLE II
Effect of operation and retesting on size choices

Group	Test	N	Per Cent Size Responses	Mean Differ- ence	t	Degrees of Freedom	Probability of Occurrence by Chance
Normal (I and II)	1	30	74.8	-1.9	0.731	45	47%
Pre-operated	1	17	80.5		0.158	14	87%
Normal	1	15	75.5			14	29%
Normal	2	15	73.6				
Post-operated	1	15	74.2	9.0	1.111	14	29%
Post-operated	2	15	83.2		1.055	14	
Post-operated	2	15	83.2				
Normal	2	15	73.6				
Pre-operated	1	17	80.5	6.9	0.683	30	50%
Normal	2	15	73.6				
Pre-operated	1	17	80.5				
Post-operated	2	15	83.2				

In evaluating the effect of operation and retesting, the size and brightness choices were considered separately. For each, the data on percentage preferences were used in two ways: (1) inter- and intra-group comparisons were made of the mean percentage preferences, and (2) inter- and intra-group comparisons were made of the variability in preference.¹⁰ The mean percentage comparisons should give information as to the

groups become more homogeneous with respect to the variable.

The results for the size percentage preferences, given in Table 11 will be considered first. These data show that there is a negligible reduction of the percentage preferences with retesting, whereas operation tends to increase the preferences slightly for the cards containing the larger figure. The reliability of the Null Hypothesis does not approach the level of significance in any of the inter- and intra-group comparisons.

The Post-operated Group (Table 12)

¹⁰ To test the variability, the variance ratio F was used. $F = \sigma_1^2/\sigma_2^2$ in which $\sigma_1^2 = \sum d_1^2/n_1$ and $\sigma_2^2 = \sum d_2^2/n_2 - 1$. Snedecor's table for F (Lindquist, 41, pp. 62-66) was used to estimate the significance of F .

TABLE 12
Effect of operation and retesting on group variability with respect to size choices

Group	Test	N	Per Cent Size Responses	Variance	Variance Ratio F-test	Reliability
Normal (I and II)	1	30	74.8	828.6	1.35	>5%
Pre-operated	1	17	80.5	614.8		
Normal	1	15	75.5	645.7	1.60	>5%
Normal	2	15	73.6	1034.3		
Post-operated	1	15	74.2	1066.6	4.86	<1%
Post-operated	2	15	83.2	219.3		
Post-operated	2	15	83.2	219.3	4.72	<1%
Normal	2	15	73.6	1034.3		
Pre-operated	1	17	80.5	614.8	1.68	>5%
Normal	2	15	73.6	1034.3		
Pre-operated	1	17	80.5	614.8	2.80	<5%
Post-operated	2	15	83.2	219.3		

TABLE 13
Effect of operation and retesting on brightness choices

Group	Test	N	Per Cent Brightness Responses	Mean Differ- ence	t	Degrees of Freedom	Probability of Occurrence of Chance
Normal (I and II)	1	30	86.8	7.1	0.973	45	37%
Pre-operated	1	17	93.9				
Normal	1	15	91.5	-22.4	2.435	14	3%
Normal	2	15	69.1				
Post-operated	1	15	82.2	10.4	1.238	14	24%
Post-operated	2	15	92.6				
Post-operated	2	15	92.6	23.5	2.355	28	3%
Normal	2	15	69.1				
Pre-operated	1	17	93.9	24.8	2.583	30	2%
Normal	2	15	69.1				
Pre-operated	1	17	93.9	1.3	0.709	30	49%
Post-operated	2	15	92.6				

for its second test compared with its first test, shows a significant decrease in variance, and hence a decrease in the individual differences of the group with respect to these choices after operation. Inter-group comparisons of the Normal Group and the Post-operated Group on the second test again show a reduction in the variance with operation. The normal animals (Normal Group and Post-

which is influenced by retesting as well as operation, shows an insignificant increase of 10.4 per cent. On the second test, the Post-operated Group shows 23.5 per cent greater preference than the Normal Group on its second test. This difference is probably significant. In summary, retesting tends to reduce the brightness preferences significantly, whereas operation works in the opposite

TABLE 14
Effect of operation and retesting on group variability with respect to brightness choices

Group	Test	N	Per Cent Brightness Responses	Variance	Variance Ratio F-test	Reliability
Normal (I and II)	1	30	86.8	898.3	17.3	<1%
Pre-operated	1	17	93.9	52.0		
Normal	1	15	91.5	654.9	2.3	>5%
Normal	2	15	69.1	1531.0		
Post-operated	1	15	82.2	1147.7	23.2	<1%
Post-operated	2	15	92.6	49.4		
Post-operated	2	15	92.6	49.4	31.0	<1%
Normal	2	15	69.1	1531.0		
Pre-operated	1	17	93.9	43.0	35.6	<1%
Normal	2	15	69.1	1531.0		
Pre-operated	1	17	93.9	52.0	1.1	>5%
Post-operated	2	15	92.6	49.4		

operated Group) show a greater variance than the Pre-operated Group, but the difference in variance is not significant.

The corresponding comparisons given for brightness percentage preferences in Table 13 show that retesting results in a relative reduction in percentage preference, which is probably significant. Operation, on the other hand, tends to increase the brightness percentage preferences. The Normal Group shows a significant reduction of 22.4 per cent with retesting. The Post-operated Group,

direction, i.e., slightly increases the percentage of brightness preferences.

Inter- and intra-group comparisons of variance (Table 14) show that the animals that have been subjected to operation are significantly less variable than normal animals. Retesting tends to have the opposite effect on the group variance, i.e., increases individual differences; the Normal Group is more variable on its second test with respect to the brightness choices than it is on its first test, although this difference is not significant.

The differential effects of operation and retesting on the size and brightness preferences may also be evaluated by considering the pairs that appear especially diagnostic. By a diagnostic pair is meant a pair which is dropped as equivalent by the normal animals on retesting, and which is added as equivalent by the animals which had undergone operations. By comparing the average percentage difference in Tables 3 and 4, it will be seen that there are 5 pairs which are diagnostic: 3, 9, 18, 20, and 21. That is, the Normal Group shows a reduction in the percentage of animals reacting to these pairs as equivalent, whereas the Post-operated Group shows an increase in the percentage of animals reacting to these same pairs as equivalent from first test to second test.

The next step is to examine the nature of these diagnostic pairs in relation to the preferences. The preferred card of pairs 3 and 9 is represented symbolically by $\overline{SBF}$ (See Table 9); of pair 18, $\overline{SBF}$; of pair 20, $\overline{SBF}$; and of pair 21, $\overline{SBF}$. It will be noted that in all four of the pairs where a brightness choice is possible, the darker card is preferred by all animals. In pair 20, where size and brightness are opposed, the majority of the animals choose in accordance with brightness, i.e., prefer the darker card. If any animal had chosen only these diagnostic pairs as equivalent, the animal would be showing a 100 per cent brightness preference, and a 75 per cent size preference. Thus, if an animal were to choose this group of cards it would be considered that the animal was responding primarily in terms of brightness.

Since the Post-operated Group chooses more of these pairs after operation, it may be concluded that the operation has increased the tendency of the animals

to choose in terms of brightness. Since the Normal Group chooses fewer of these cards with retesting, it may be concluded that there is a decrease in the tendency to choose in terms of brightness.

These data suggest that with retesting there is a decrease in the importance of the brightness aspect, and with operation there is an increase in the importance of the brightness aspect.

In general, the size preferences are slightly less affected by operation, and markedly less affected by retesting than the brightness preferences, with respect to both measures, mean percentage preference and group variability of preferences. Retesting tends to decrease the brightness preferences significantly, but does not affect the size preference. Operation tends to increase the brightness preferences markedly, but has only a slight tendency to increase the size preferences. The same conclusions can be reached by an analysis of the diagnostic pairs. Furthermore, retesting tends to increase the individual differences with respect to both the brightness and size preferences. Operation tends to decrease the individual differences with respect to the size preferences, and to decrease the individual differences markedly with respect to the brightness preferences.

IV. RELATIONSHIP BETWEEN EQUIVALENCE REACTIONS AND ASPECTS OF BRAIN INJURY

Cortical injury was shown to have two striking behavioral effects: it increases the number of equivalent pairs chosen, and it increases the number of relational responses. Since the experiment was designed with the primary interest of studying the behavioral effects of cortical

injury, no systematic attempt was made to study one particular aspect of brain injury. Although the range of total extent of lesion was not great, and the lesions were not confined to particular loci, nevertheless, the brain injuries suffered by the animals differed in small amounts with respect to locus, shape, depth, extent of lesions and bilateral relations. For this reason, the relation between these aspects of brain injury and the behavioral effects noted above were examined.

Since the Post-operated Group was tested before and after operation, an additional variation of each of the behavioral criteria was employed for this group only: *change* in number of equivalent pairs chosen; and *change* in number of relational responses. The animals of the Pre-operated Group and the Post-operated Group were treated separately.

A. Locus of Lesion

1. *Critical Area.* To determine whether the locus of brain injury had any relation to the behavioral effects, the animals of the Pre-operated Group were separated into two groups on the basis of whether or not they chose more than the mean number of equivalent pairs. The lesion diagrams for the groups choosing *more* than the mean number of equivalent pairs were superimposed to determine whether common areas had been destroyed. Such a common area was found in each hemisphere. In order for these common areas to be considered critical areas, it would be necessary to demonstrate that the rats of the group having low equivalence scores escaped injury in these areas. Since all of the rats of the low equivalence group had some lesion in these areas common to the high equivalence group, destruction of the

common areas cannot account for the behavioral difference between the two groups.

A similar analysis was carried out with respect to relational responses for the Pre-operated Group and all four criteria for the Post-operated Group. These analyses showed that there were no *critical* areas, which could in and of themselves, account for the behavioral differences noted.

2. *Visual Area.* Special attention was given to the visual area even though any striking effect due to the injury of this area should have been evident in the data obtained by the previous analysis. The visual areas plotted by Lashley (35) using the retrograde degeneration technique were transferred to the standard diagram. Since well defined areas were under consideration, it was possible to employ the reverse of the method used above, i.e., establish groups on the basis of whether or not the visual areas had been invaded and look for behavioral effects (rather than establishing groups on the basis of the behavioral criteria and searching for critical locus of lesion).

Since only one animal (75F) of the Pre-operated Group escaped injury to the visual areas, invasion of the visual areas cannot account for the difference in behavior of one animal as compared to another with respect to the number of equivalent pairs chosen, or the number of relational responses.

Five animals of the Post-operated Group escaped injury in the visual areas. Table 15 shows the mean and range of scores on each of the behavioral criteria for the animals that escaped injury to the visual areas and those that suffered injury to the visual areas. These data show that invasion of the visual areas is in and of itself not a critical factor in

determining the behavioral effects examined.

This analysis was designed only to discover gross effects which might be due to any injury of the visual area as opposed to no injury of the visual area. The question of extent of visual area destroyed will be considered in a later paragraph under the heading extent of lesion.

3. "S" and "V" Areas. The two master areas isolated by Krechewsky (28) which were related to spatial and visual hy-

Table 16 shows that the animals which had at least 20 per cent of area "S" destroyed and less than 20 per cent of area "V" destroyed choose more critical pairs as equivalent, and make more relational responses. The range of scores making up these comparisons, however, indicate that the differences are not sig-

TABLE 15
Effect of destruction of visual area on behavior

Behavioral Measures	Visual Area Invaded	Visual Area Not Invaded
Number of Equivalent Pairs	12.6* (1 to 19)	10.4 (1 to 18)
Change in Equivalent Pairs	3.1 (-7 to 17)	5.4 (-1 to 18)
Number of Relational Responses	2.5 (0 to 5)	1.8 (0 to 5)
Change in Relational Responses	1.0 (-2 to 5)	1.2 (0 to 4)

* The mean and range is given in each case.

potheses were also investigated in relation to the observed behavioral differences. For this purpose, the Pre-operated Group was divided into two groups according to the lesions designated as critical by Krechewsky: (1) animals having at least 20 per cent of areas "S" destroyed and less than 20 per cent of area "V" destroyed and (2) animals having more than 20 per cent of area "V" destroyed. Ten of the animals fit into the first group and 7 of the animals fit into the second group. These groups established on the basis of cortical injury suffered were then compared with respect to the behavioral criteria.

TABLE 16
Comparison of the effect of lesions in areas "S" and "V"
Pre-Operated Group
Animals having at least 20% of area "S," and less than 20% of area "V" destroyed

Rat	Number of Equivalent Pairs	Number of Relational Responses
X61F	17	3
X73M	7	0
X75F	15	2
X58F	16	2
X72F	15	3
154M	2	0
X134M	3	0
X129M	19	4
75F	5	1
X91M	14	3
Average Range	11.3 (2 to 19)	1.8 (0 to 4)

Animals having more than 20% of area "V" destroyed

Rat	Number of Equivalent Pairs	Number of Relational Responses
X84M	14	1
X130M	1	0
171F	8	0
X88M	14	3
X56M	1	0
X65M	14	2
75M	3	0
Average Range	7.9 (1 to 14)	0.9 (0 to 3)

nificant for either of the two behavioral measures.

The same procedure was followed for the Post-operated Group, except that here the two critical groups were compared on the basis of the four behavioral

criteria. Not all of the animals could be classified in this way, i.e., 3 animals had no lesion in either area. Of the remaining 12 animals, 8 had at least 20 per cent of area "S" destroyed and less than 20

groups established on the basis of brain lesions are not significant.

The analysis of the data in terms of the areas delimited by Krechevsky do not appear in and of themselves to be crucial

TABLE 17
Comparison of the effect of lesions in areas "S" and "V"
Post-Operated Group
Animals having at least 20% of area "S," and less than 20% of area "V" destroyed

Rat	Number of Equivalent Pairs	Change in Equivalent Pairs	Number of Relational Responses	Change in Relational Responses
107F	14	+7	3	+3
X78M	17	+17	2	+2
359M	11	+2	1	0
357M	17	+10	1	0
356M	17	0	3	0
X81M	11	+2	1	0
X56F	5	+4	0	0
357F	16	+5	5	+5
Average Range	13.4 (5 to 17)	+5.9 (0 to +17)	2.0 (0 to 5)	+1.9 (0 to +5)

Animals having more than 20% of area "V" destroyed

Rat	Number of Equivalent Pairs	Change in Equivalent Pairs	Number of Relational Responses	Change in Relational Responses
X74F	19	+5	4	+2
172M	9	-7	3	-2
X50M	1	-2	0	0
X83M	17	0	4	0
Average Range	10.5 (1 to 19)	-1.0 (-7 to +5)	2.8 (0 to 4)	0.0 (-2 to +2)

Animals with no lesion in area "S" or area "V"

Rat	Number of Equivalent Pairs	Change in Equivalent Pairs	Number of Relational Responses	Change in Relational Responses
76F	18	+18	2	+2
355M	1	-1	0	0
358M	1	-1	0	0
Average Range	6.7 (1 to 18)	+5.3 (-1 to +18)	0.7 (0 to 2)	+0.7 (0 to +2)

per cent of area "V" destroyed. The groups divided on the basis of lesions in the critical areas are compared in Table 17. The overlapping of scores of the two critical groups indicates that the behavioral differences between the

areas with respect to the equivalence behavior observed in this study.

B. Shape of Lesion

Since the shape of the brain lesion has been reported (Maier, 41; Maier and

Sabom, 47) to be an important factor related to certain kinds of behavioral deterioration, and since the brain lesions of the animals in this study vary in shape, the effect of this factor was evaluated in relation to the behavioral results. The procedure followed was to express the shape of lesion as a ratio of

animal with highest number of equivalent pairs and the highest number of relational responses was given the first rank. The distribution of rank order for shape was correlated with each of the behavioral criteria, number of equivalent pairs chosen, and number of relational responses. The correlations be-

TABLE 18
Relation between aspects of brain injury and behavior
Pre-Operated Group

Rat	Brain Injury					Behavior	
	Visual Area Lesion	Total Lesion	Common Lesion	Bilateral Extent Ratio	Shape	Number of Equivalent Pairs	Number of Relational Responses
X84M	66.3	31.2	20.4	1.81	2.34	14	1
X61F	35.9	26.5	20.9	1.15	2.34	17	3
X130M	68.5	24.6	21.7	1.13	2.41	1	0
171F	60.9	24.1	17.5	1.18	2.15	8	0
X88M	48.9	23.9	19.2	1.16	2.42	14	3
X56M	54.4	21.4	15.3	1.35	1.39	1	0
X73M	48.9	21.1	16.7	1.01	2.82	7	0
X75F	14.1	20.2	15.3	1.56	2.08	15	2
X58F	10.9	19.3	17.5	1.15	2.57	16	2
X72F	19.6	17.5	14.0	1.18	3.26	15	3
X65M	81.5	17.4	13.5	1.10	1.33	14	2
154M	45.7	16.9	10.8	1.49	1.52	2	0
X134M	32.6	16.8	11.1	1.72	2.63	3	0
X120M	16.3	14.5	9.8	1.11	2.10	19	4
75M	82.6	14.4	10.3	1.13	1.14	3	0
75F	0.0	11.8	7.4	1.13	1.48	5	1
X91M	21.7	11.2	10.6	1.02	3.43	14	3
Mean	41.7	19.6	14.8	1.26	2.20	9.9	1.4

length to width.¹¹ The animals of the Pre-operated Group were ranked (Table 18) according to the shape of lesion, i.e., the animal with the highest ratio was given the first rank. The animals were ranked with respect to each of the behavioral criteria separately such that the

tween shape and number of equivalent pairs, and shape and number of relational responses are given in Table 19 for the Pre-operated Group. The correlations are low, positive, and not reliable.

The animals of the Post-operated Group were treated in the same way, but in this case there are four correlations. The two *change* criteria, *change* in number of equivalent pairs chosen, and *change* in number of relational responses, were used in addition to number of equivalent pairs chosen and number of relational responses. In an analogous way, the ani-

¹¹ In the study by Maier and Sabom (47), the direction of the longer axis was found to be unimportant and the ratios could be expressed by values of 1 or greater by dividing the longer axis by the shorter one. All but 2 rats in this study, 1 in the Post-operated Group, and 1 in the Pre-operated Group, had lesions which were longer than they were wide. These animals maintain the same relative rank, whichever of the two methods of expressing shape were used.

TABLE 19
Correlations between aspects of behavior and of brain injury
Pre-Operated Group

	Total Lesion	Common Lesion	Shape	Visual Area	Depth	Bilateral Extent Ratio
Number of Equivalent Pairs	$+.06 \pm .17$	$+.09 \pm .17$	$+.27 \pm .16$	$-.47 \pm .13$	$-.23 \pm .16$	$+.14 \pm .17$
Number of Relational Response	$-.07 \pm .17$	$-.01 \pm .17$	$+.30 \pm .16$	$-.42 \pm .14$	$-.40 \pm .14$	$+.26 \pm .16$

mals having the greatest positive *change* was given rank 1 (Table 20), and the animal with the greatest negative change was given the lowest rank. The correlations between shape and all four criteria for the Post-operated Group given in Table 21 indicate that there is no evidence of any relationship between shape of lesion and any of the behavioral criteria.

These data indicate that for both the Pre-operated Group and the Post-

operated Group there is no evidence of any relationship between shape of lesion and the behavioral criteria examined.

C. Depth of Lesion

There are two aspects of depth of lesion that should be considered, depth within cortical tissue, and depth of sub-cortical injury.

1. Depth Within Cortical Tissue.

Examination of the lesions showed that whenever the cortex was injured at all,

TABLE 20
Relation between aspects of brain injury and behavior
Post-Operated Group

Rat	Brain Injury					Behavior			
	Visual Area Lesion	Total Lesion	Common Lesion	Bilateral Extent Ratio	Shape	Number of Equivalent Pairs	Change in Equivalent Pairs	Number of Relational Pairs	Change in Relational Pairs
X74F	53.3	24.9	22.9	1.13	2.4	19	+5	4	+2
X107F	28.3	24.0	18.0	1.29	2.4	14	+7	3	+3
172M	69.6	23.3	13.8	1.17	2.4	9	-7	3	-2
X59M	56.5	23.3	18.7	1.30	2.9	1	-2	0	0
X78M	44.6	22.8	18.0	1.18	2.2	17	+17	2	+2
X81M	44.6	21.9	19.0	1.28	2.9	11	+2	1	0
X83M	58.7	19.1	13.1	1.92	2.7	17	0	4	0
X56F	32.6	18.4	16.7	1.16	2.4	5	+4	0	0
76F	3.3	16.0	14.0	1.24	1.4	18	+18	2	+2
357F	57.6	15.9	13.3	1.02	2.0	16	+5	5	+5
359M	0.0	14.3	10.8	1.27	1.9	15	+1	2	0
357M	0.0	12.9	10.6	1.02	1.7	17	+10	5	+4
356M	28.3	11.1	7.9	1.04	1.6	17	0	3	0
355M	0.0	9.9	8.4	1.28	0.9	1	-1	0	0
358M	0.0	7.4	4.9	1.39	1.4	1	-1	0	0
Mean	31.8	17.7	14.0	1.25	2.08	11.9	+3.9	2.3	+1.1

TABLE 21
Correlations between aspects of behavior and of brain injury
Post-Operated Group

	Total Lesion	Common Lesion	Shape	Visual Area	Depth	Bilateral Extent Ratio
Number of Equivalent Pairs	$+.20 \pm .18$	$+.17 \pm .18$	$-.05 \pm .18$	$+.13 \pm .18$	$+.02 \pm .18$	$+.46 \pm .14$
Change in Equivalent Pairs	$+.15 \pm .18$	$+.31 \pm .16$	$-.12 \pm .18$	$-.18 \pm .18$	$-.04 \pm .18$	$+.41 \pm .15$
Number of Relational Responses	$+.20 \pm .18$	$-.01 \pm .18$	$+.09 \pm .18$	$+.34 \pm .16$	$-.01 \pm .18$	$+.53 \pm .13$
Change in Relational Responses	$+.16 \pm .18$	$+.24 \pm .17$	$-.07 \pm .18$	$-.03 \pm .18$	$-.03 \pm .18$	$+.46 \pm .14$

the lesion included the entire thickness of the cortex, and thus the differential behavioral effects cannot be accounted for by differences in depth of lesion within cortical tissue.

2. *Depth of Sub-cortical Injury.* To examine the effect of sub-cortical injury, the depth of subcortical injuries were

rated, separately for the anterior third, central third, and posterior third of the brain. A "0" indicates no injury; "1" indicates very slight injury; "2" indicates slight injury; and "3" indicates considerable injury. These ratings were then added together to give a total rating value for each animal, taking into ac-

TABLE 22
Ratings of sub-cortical destruction

Post-operated Group					Pre-operated Group				
Rat	Anterior Third	Central Third	Posterior Third	Total Rating	Rat	Anterior Third	Central Third	Posterior Third	Rating
X74F	2	3	2	7	X84M	3	3	2	8
X107F	2	2	0	4	X61F	3	2	0	5
172M	2	3	3	8	X130M	1	1	1	3
X59M	1	3	2	6	171F	2	3	2	7
X78M	2	2	1	5	X88M	0	2	1	3
X81M	1	1	0	2	X56M	1	3	1	5
X83M	1	1	1	3	X73M	1	2	1	4
X56F	1	2	1	4	X75F	1	1	0	2
76F	2	0	0	2	X58F	1	2	1	4
357F	0	1	0	1	X72F	2	1	0	3
359M	1	0	0	1	X65M	0	2	1	3
357M	1	1	0	2	154M	0	3	2	5
356M	0	1	0	1	X134M	1	2	1	4
355M	2	0	0	2	X129M	0	1	1	2
358M	1	0	0	1	75M	0	2	1	3
					75F	2	2	0	4
					X91M	0	0	0	0
Mean	1.3	1.3	0.7	3.3	Mean	1.1	1.9	0.9	3.8

count injuries of the entire brain. The ratings, thus, could range from "0" representing no sub-cortical injury to "9" indicating considerable injury to all parts of the brain. These ratings are given in Table 22.

It will be seen that the animals of the Pre-operated Group and the Post-operated Group were treated separately. The animals of each of these groups were ranked from most to least in accordance with subcortical injury, and the distribution of ranks were correlated for each of the behavioral criteria. The correlations between depth of subcortical injury and the behavioral criteria are given for the Pre-operated Group in Table 19, and for the Post-operated Group in Table 21.

The Pre-operated Group had low negative correlations between subcortical injury and the behavior criteria. The Post-operated Group had correlations of zero-magnitude between depth of sub-cortical injury and the behavioral criteria.

These data indicate that there is no relation apparent between depth of subcortical injury and any of the behavioral criteria examined.

D. Extent of Lesion

In all cases the relationship between extent of cortical injury and the behavioral criteria was ascertained by correlating the distribution of ranks for each behavioral criterion of the animals of each group separately with the measures of extent described below.

1. *Total Lesion.* By total lesion is meant the total percentage of destruction suffered by the operated animals in both hemispheres (See Plate 2). The total extent of lesion was not very great for either operated group. For the Pre-operated Group the average total lesion

was 19.6 per cent and for the Post-operated Group the average total lesion was 17.7 per cent. The correlations between total lesion and the behavioral criteria are given in Table 19 for the Pre-operated Group, and in Table 21 for the Post-operated Group.

There is no evidence for any relationship between any of the behavioral criteria and total lesion in the Pre-operated Group. The highest correlation between total lesion and a behavioral criterion was found in the Post-operated Group ($+.20 \pm .18$) for the criterion, number of equivalent pairs. At best, then, the correlations are low, positive, and not reliable.

For these data there is no relation apparent between total lesion in and of itself and any of the behavioral criteria examined.

2. *Visual Area.* Here the attempt was made to determine whether extent of visual area destroyed was related to any of the behavioral criteria. The extent of visual area destroyed was calculated by superimposing the visual areas delimited by Lashley (35), and finding the percentage of visual area destroyed in each animal by use of the planimeter. The animals of each group were ranked separately from most to least destruction in the visual area, and it was this distribution of ranks that was correlated with the distributions based on the behavioral criteria.

Table 19 shows that for the Pre-operated Group there is a low negative correlation between extent of destruction in the visual area and number of equivalent pairs chosen, and also a negative correlation between extent of destruction in the visual area and number of relational responses.

In the Post-operated Group (Table

21) there is a low positive correlation between extent of destruction of visual area and number of equivalent pairs, and between extent of destruction of visual area and number of relational responses. The correlations, on the other hand, are low and negative between extent destruction of visual area and both the "change" criteria.

Since the correlations are low, and negative in some instances and positive in others, there does not seem to be any relationship between extent of visual area destroyed in and of itself and the behavioral effects examined.

E. Bilateral relations

1. *Common Lesion.* Examination of Plate 2, will show that the brain lesions suffered by the animals are never exactly bilaterally symmetrical with respect to locus. It is conceivable that in order to be effective, bilateral lesions must destroy corresponding (functional) areas in the two hemispheres. To investigate this possibility roughly (there is no guarantee that anatomically identical areas are functionally identical), the areas destroyed in the two hemispheres were superimposed for each animal. The area destroyed common to both hemispheres was delimited (Plate 2) and the extent of common lesions was calculated (Tables 18, and 20).

For the Pre-operated Group the values for rho (Table 19) between the distribution of ranks of extent of common lesion, and the distribution of ranks of the behavioral criteria show no evidence of any relationship.

The same is true for the Post-operated Group (Table 21).

2. *Bilateral Extent Ratio.* The attempt was also made to see whether there was any relationship between the behavioral

criteria and a measure of bilateral relations of mass of tissue destroyed. The bilateral *extent ratio* was calculated by finding the ratio of extent destruction in the hemisphere with the *greater* destruction to the extent destruction in the hemisphere with less destruction. This cancels out any effect due to total extent. If the extent destroyed in one hemisphere was equal to the extent destroyed in the other hemisphere, then the ratio was 1.00. On the other hand, if the extent of tissue destroyed in one hemisphere was *not* equal to that destroyed in the other hemisphere, then the ratio was greater than 1.00. The lower the ratio, the greater the bilateral symmetry of the lesions with respect to *extent*.

To test the effect of bilateral extent ratio of lesions, the animals with the *lowest* ratio were given the *highest* rank, i.e., the animal with the most symmetrical lesions with respect to extent was given the highest rank (see Tables 18, and 20). The distribution of ranks for the bilateral extent ratio measure was then correlated with the distribution of ranks of each of the behavioral criteria for the Pre-operated and Post-operated Groups separately.

The correlations given in Tables 19 and 21 show that both the Preoperated Group and the Post-operated Group have positive correlations of bilateral extent ratio with all of the behavioral criteria. The correlations for the Post-operated Group show a more intimate relation between the behavioral criteria and this aspect of operation, than any of the other aspects studied. Furthermore, the only reliable correlation which has been obtained in this section is that of $+.53 \pm .13$ between bilateral extent ratio and number of relational responses. This as-

pect of operation is the only one in which all behavioral criteria are appreciable in magnitude and consistent in direction.

Taking the entire picture into consideration there is only a suggestion that when the lesions are more symmetrical with respect to mass, they are more effective in producing the behavioral changes.

Before interpreting these data, it must be kept in mind that the amount of

cortical destruction was relatively small even in cases with the most destruction, and secondly, that the analysis was made between the behavioral criteria and each aspect of cortical injury, in and of itself.

The attempt was also made to combine together several aspects of brain injury, such as shape, extent and bilateral relations, to see whether there was any relation between a combined measure and the behavioral criteria. All such attempts met with no success.

DISCUSSION

THE most striking generalization that can be made when the results are considered in relation to each other is that cortical injury and retesting (experience) have differential effects on equivalence behavior.

The factors of operation and retesting were considered in relation to three important behavioral criteria: number of equivalent pairs chosen, relational responses, and preferences. It was found that the number of equivalent pairs chosen increased with cortical injury. This result corresponds to that found by Maier (45) in his study utilizing a different training pair. When discussing his results, Maier indicated that the tendency of operation to increase the number of equivalent pairs chosen could not be generalized, because it might be an effect limited to the training pair he employed. Since the result was confirmed in the present study with similar techniques, but utilizing a different training pair, there is a definite indication of a consistent effect of operation on equivalence behavior.

Halstead's work (9, 10) with human beings is of interest in this connection. Using a grouping test based on the method of equivalent and non-equivalent stimuli, he found that patients with lesions in the frontal lobes grouped a smaller percentage of objects and generally utilized fewer categories as compared with either normal subjects or patients with extra-frontal lesions. Strauss and Werner (60), on the other hand, used a similar sorting test, but obtained a result which was contradictory to Halstead's. In their study, brain injured (exogenous) children grouped a larger percentage of objects than either mentally retarded (endogenous) children or

normal children. Strauss and Werner's work appears to be in closer harmony with the results obtained in this study than do Halstead's.

In contrast to the effect of cortical injury, it has been demonstrated that the total number of equivalent pairs was not altered with retesting. Maier (45), however, found that for a discrimination involving a figure-ground difference, rats showed a decrease in number of equivalent pairs chosen with retesting. The procedures of Maier's study and the present investigation did not differ markedly. However, there were two differences which might account for the discrepancy. In the first place, Maier's study utilized 13 critical pairs, whereas the present investigation used 23 critical pairs. The greater length of the critical series and the attempt to test relational responses sometimes demanded the use of certain cards in more than one critical pair, which means that due to the prolonged testing period, the rats had considerable opportunity to learn to react to the absolute properties of these cards. Whenever a critical pair containing this card would be presented, the rats might capitalize on their previous experience and make consistent responses to the card. Thus, the total number of equivalent pairs would be inflated. This effect might be extensive enough to mask a decrease in number of equivalent pairs which would otherwise be observed with a shorter critical series having less duplication of individual cards.

In a more important respect, the two studies show fundamental agreement, i.e., with regard to the role of relational properties. Both lead to the conclusion that retesting results in decreased importance of the general and relative features

of the training pair. In the present study retesting resulted in a slight decrease in number of relational responses. Maier (45) found that "... continued familiarity with a situation tends to increase reactions to difference, and as a consequence the absolute properties of the training situation increase in importance" (p. 181).

The two studies also agree as to the effect of cortical injury on importance of relational properties, and further agree that the effect of operation is opposite to the effect of retesting. In the present experiment, cortical injury produced an increase in the number of relational responses. These data provide further experimental confirmation of Maier's suggestion that "Cerebral injury seems to decrease reactions to detail so that general and relative features become important" (45, pp. 181-82).

Extensive analysis of the present results as to the basis of the discrimination showed that neither brightness nor size alone determined the preferences, but some combination of the two was operative, with brightness assuming the dominant role, on first test. Maier's (43) results on first test of normal animals using the same training pair employed in this experiment, likewise showed that both brightness and size determined the preference. Owing to the small number of equivalence reactions, however, Maier did not analyze his results in terms of the relative importance of the two factors, as was done in this experiment.

Certain results as to the properties determining choices in visual discriminations obtained by Lashley (36) on normal animals are in harmony with those obtained by Maier and those reported above. Lashley likewise used a "size" discrimination and a wide variety of critical

tests. He concluded that "... during initial training with 'size' at least some of the animals acquired the capacity to react independently to linear dimensions, to surface area, and to total reflected light and were able to recognize these attributes when presented separately" (36, p. 169). Lashley used white figures on black backgrounds, while Maier and the present investigator used black figures on gray backgrounds. The experiments differed in other respects as well, but all three came to similar conclusions. When an animal is first presented with a pair of cards which differ with respect to size, but which also differ with respect to other attributes, size alone does not determine the preferences, but a combination of properties is operative. The present study further shows that if a difference in total amount of reflected light exists as well as differences in size of figure and other properties, it is probable that the first property will assume the dominant role.

Although human beings confronted with the original training pair used in this experiment characterize it immediately as a size discrimination, the rat's initial reaction, on the contrary, as indicated above, appears to be primarily in terms of "brightness." The equivalence method is particularly adapted to revealing just such perceptual differences between animal forms.

The preferences, too, were affected by both retesting and operation, but in opposite directions. On retesting, the importance of total brightness, which was the dominant factor on first test of normal animals, decreased to the point where it became less important than size. Since the influence of size remained almost constant, size became the dominant factor determining the preference

of normal animals on retesting. On the contrary, after operation, the tendency to react in terms of "brightness" was slightly increased.

Further, it was found that with retesting there was a slight *increase* in the individual differences with respect to the size and brightness preferences. With cerebral injury, on the other hand, the individual differences significantly *decreased* with respect to the size and brightness preferences. These facts have interest value with respect to the differential effects of operation and retesting, and as a verification of the fact that operated animals are less variable as a group.

The relational response findings can be combined with the preference data to make a more exact analysis of the behavior of the animals after cortical injury. With operation, the animals show a slight tendency to increase in "brightness" preferences, and a definite tendency to increase in relational responses. The effect of retesting, on the other hand, is to decrease brightness preferences as well as relational responses. Apparently after operation, both "brightness" preferences and relational responses show the same relationships, i.e., increase. With retesting both "brightness" preferences and relational responses again show the same relationships, but in this case, decrease. Since either variable, operation or retesting, acts in the same way on "brightness" preferences and relational responses, the inference can be made that when the animals respond to relations they do so in terms of "brightness" relations, i.e., they go to the totally "darker" of two cards.

The redistribution of equivalence choices after operation may be related to the increase in "brightness" prefer-

ences and the increase in relational responses. The redistribution of equivalence choices after retesting, on the other hand, may be related to the decrease in "brightness" preferences and the decrease in relational responses.

In contrast to the marked effect of factors within the individual (operation and experience) on equivalence reactions, variation of factors in the situation were shown to be ineffective in altering equivalence reactions. Certain investigators (Dunlap, 2; Lashley, 36; Maier, 43; and others) have emphasized the importance of individual differences in learning situations. Two individuals exposed to the same situation do not necessarily react in the same way. In so far as experience and brain injury alter the nature of the individual, it is to be expected that variation of these factors will have a marked effect on equivalence reactions of the individual animal. But more important, it has been shown that basically these two factors have opposite effects, and that these effects are not specific to a particular training pair.

Since the differential effects of operation and retesting have general application for equivalence behavior, the implication of these data for theoretical issues is of interest.

The method of equivalence has enabled us to identify relational responses as an important feature of discrimination. The fact, of course, has been observed by other investigators. In this experiment, the rats learned a discrimination and showed some evidence of response in relational terms when subsequently exposed to new stimuli and configurations. This sequence resembles closely the sequence of behavior characterized by many authors (Fields, 3; Munn and Stiening, 52; Gellerman, 4; etc.) as

generalization, abstraction, and concept formation, i.e., as the capacity to respond to form *per se* regardless of size, orientation, position, and pattern complexity. The response of form *per se*, like the response to "brightness relations" involves the principle of reacting to the relational properties common to a series of heterogeneous stimulus situations. This type of behavior, especially when found in lower animals, has been regarded by many workers as evidence for a higher mental process.

An additional fact has been presented in the course of the discussion of the results, however, which precludes any possibility of interpreting the relational aspects of equivalence behavior as a higher mental process, namely, the fact that the partially decorticated animals show more evidence of relational responses, and choose a greater number of pairs as equivalent than do intact animals. It is illogical to suppose that a partially decorticate rat utilizes higher levels of behavior than a normal one. Maier (40) for example, has shown that reasoning definitely deteriorates after brain injury. At any rate, behavior which is not only unimpaired, but which actually increases in frequency after cortical injury cannot be considered to have as its basis a higher mental process.

The other data do certainly appear to indicate that the operated animals behave in a more primitive way after operation than before, since they show an increased dependence on "brightness" rather than size, and "brightness" is generally considered a more primitive cue than size. Further evidence for this contention may be found in the result that the operated animals become less variable as a group with respect to their "brightness" preferences.

If one considers generalization as the process of recognizing and reacting to the common properties in two or more stimulus situations, then the relational behavior observed in this study simulates generalization. But this is no guarantee that it is a product of some higher mental process as many workers believe. The evidence of the present experiment indicates that it is relatively primitive, and Lashley (37) and Koffka (26) and a few others are the only investigators who have specifically recognized this fact.

The results of other investigations that show that these "generalizations" or transpositional or relational responses occur at low phylogenetic levels may be adduced as further evidence to support the conclusion of this study that such relational behavior is primitive. To give a few examples, Perkins and Wheeler (54), and Meesters (50) have demonstrated relational behavior in fish. The well known experiments of Köhler (24) have demonstrated relational responses in chickens. Moody (51) found that mice were unable to learn a brightness discrimination when the two stimuli were not visible simultaneously; but when the mice were permitted to compare the two stimuli (by changing the apparatus), the same discrimination was learned readily. Hebb (11) has shown that relational responses persist after total destruction of the striate cortex in rats. Klüver and Bucy (23) have shown that the capacity to make these "generalizations" persist after bilateral temporal lobectomy in monkeys. Klüver (22) has demonstrated that they persist after removal of the occipital lobes in monkeys. According to Lashley (37) such relational, transpositional responses, or "generalizations" are as primitive as discrimination itself.

The confusion with higher mental processes has been unfortunate. If one considers that the end results of many processes may appear the same, the reason for confusion in terminology becomes apparent. The result in one case may be a product of abstraction or of some higher mental process, and in another the result of some more primitive type of perceptual process, but the end result in each case would be generalized behavior. If we suppose this is to be the case, it would be better to consider levels of generalization rather than a unitary process of "generalization." Since the behavior described here occurs on a perceptual level, it will hereafter be referred to as perceptual generalization, where "generalization" refers to behavior characterized by reaction to the common properties in two or more stimulus situations. In accordance with this viewpoint there may be many behavior sequences which would be characterized as generalizations. In addition to the perceptual generalization observed in this experiment there might be other *kinds* of generalization, such as those arrived at by a reasoning process, where there may even be an awareness of the relationships involved. The underlying processes then would characterize the *kind* of generalization.

There have been quite a few investigators who have recognized the confusion which has hovered around the concepts of abstraction, generalization, and concept formation, and who have attempted to deal with it by postulating something analogous to what we have considered here as levels of generalization. Maier (45) for example, indicates "... that the transfer of responses to new situations may depend upon two processes, (a) reactions to likeness alone, and

(b) abstraction, which involves a balance between reactions to likenesses and differences" (p. 179). Thus, in attempting to account for equivalence reactions he distinguishes between two entirely different processes.

Werner (62) discusses what he terms analogous levels of abstraction. He postulates three such levels: (1) Relationship on a sensori-motor level, which is best exemplified by Köhler's transposition experiments in chicks. (2) Relationship on a predominantly perceptual level, which is exemplified by Line's (see 60, pp. 219-21) card-sorting experiments, where the problem is to sort cards on the basis of whether they reveal a relation of concrete sameness or difference. (3) Relationship on the level of abstraction. For Werner, abstraction consists of a mental activity where the parts of a situation are separated from the whole, and these detached qualities are experienced in isolated fashion.

The attempt of Goldstein and his collaborators (6, 7, 8) to separate abstract from concrete behavior may be considered a step in the same direction. Goldstein and Sheerer (8), for example, point out in discussing the studies on perceptual stages in children and adults, that it is not necessary "... to assume processes of involuntary abstraction as long as it suffices to explain the reactions as due to *phenomenal* groupings, be it that they arise spontaneously in response to a field or through a training effect" (p. 23).

In discussing primitive forms of abstraction, Lashley (36) says that, "The problem of the evolution of the capacity for generalization is really the question of the kinds of properties or relations between objects with which animals of different evolutionary levels can deal"

(p. 163). Lashley goes so far as to mention at least two orders of generalization. The first is a kind of situation where the adequate stimulus is a relational property of direction, distance, size, etc. Under generalizations of the second order, he includes cases in which two variables must be reacted to simultaneously, or cases where one variable determines the reaction of another.

The analyses by these workers lend support to the view that is presented here. To repeat, generalization, as defined above, is a product of perhaps two or more qualitatively different processes. The generalizations observed in this study, and those of a similar kind observed by other workers fit into the class of perceptual generalizations. They are called "perceptual" since they seem to depend on the character of the perceptual organization inherent in the animal form studied.

Wheeler (63) and Helson (12) have considered response to a relationship as a criterion of insight. If by insight they mean to imply some higher mental process, then this position is inconsistent with the facts presented here. It is worthy of specific mention that Köhler¹² does not regard transposition alone, as evidence that insight has occurred. As Köhler defines insight, it is necessarily concerned with an awareness of relations, and he doubts whether an animal who chooses relationally and therefore tends to transpose, need be aware of the fact that his choice is relative.

It has been definitely established that certain behavioral effects occur following cortical injury, but the results already presented show that it is difficult to isolate the specific aspects of the lesions

which are crucial for the changes in behavior.

None of the behavioral criteria showed any relation to locus of cortical lesion. In a very similar situation, Maier (45) also failed to find any localization effect. With human patients on a sorting test, Halstead (9, 10), however, found behavioral differences corresponding to differences in locus (previously discussed on p. 76). The frontal lobe lesion cases showed differences not only from normal subjects, but from patients having extra-frontal lesions (parietal, occipital, and temporal lobe cases). However, Halstead's experiments used human subjects whereas the other two used rats. The discrepancy might be explained by increasing cortical specialization with ascendance of the phylogenetic scale.

Maier (45) found evidence of a reliable positive correlation between extent of lesion and increase in number of equivalent pairs after operation, which was not obtained in this study. Since the experimental designs were essentially the same in the two studies, some analysis is required to account for the difference in result. In the present study only one aspect of brain injury explored, bilateral extent ratio, showed any suggestion of a relationship with the behavioral criteria. When bilateral extent ratio is examined closely, it becomes apparent that, in and of itself, the ratio is not a primary aspect of brain injury. It is a secondary measure in the sense that it depends on the ratio of extent of cortical injury in one hemisphere to the extent of cortical injury in the other hemisphere. As has already been indicated, other things being equal, the more symmetrical the lesion with respect to extent, the greater the behavioral changes observed.

Since there appears to be a relation-

¹² Personal communication.

ship between total lesion and increase in equivalent pairs chosen, as Maier's data indicate, we might expect an animal with a comparatively large total lesion to choose a greater number of equivalent pairs than an animal with a relatively small total lesion. However, if the animal with the large lesion had a high percentage of the total lesion in one hemisphere, and if the factor of bilateral symmetry of extent, as our data suggest, was operating in addition to the factor of total extent destroyed, then in this case the two factors would operate in opposite directions. For this reason the animal with the large total lesions would not necessarily choose a greater number of pairs as equivalent than the animal with the small total lesion. Under these conditions, the measure, total extent of lesion, taken by itself would not show any evidence of a relationship with the behavioral criterion, number of equivalent pairs.

The asymmetry of the lesions with respect to *extent* and the small size of the total lesions may be the complicating factors which account for our failure to obtain evidence of a reliable positive correlation between total extent of injury and increase in number of equivalent pairs.

Confining our remarks to an animal form like the rat, it is clear that the relationship between brain injury and behavioral deterioration is a complicated one. If one merely removes a small amount of cortical tissue from a rat's brain, the injury involves a multiple variable situation. Nevertheless, many investigators have shown that some of these variables, extent (Lashley, 30, and others), locus (Stellar, Morgan, and Yarosh, 59), shape (Maier, 41; Maier and Sabom, 47), even when considered by

themselves, are related to certain kinds of behavioral deterioration.

In some cases the particular aspect of the lesion that is important is determined by the nature of the problem set for the animal, but even within a particular kind of problem, a multiple variable situation exists, for example, Krechevsky's (28) work with master areas, where a minimum of 20 per cent of tissue had to be destroyed for a particular locus to determine the preferences; or Maier's work on reasoning, where behavior deterioration was determined, not only by a minimum amount of total lesion (40), but also by the shape of the lesion (Maier, 41; Maier and Sabom, 47) or the work on complex discrimination habits by Lashley (33) where there was a relationship to extent of lesion within a particular locus.

There is some suggestion from the present investigation that the bilateral extent relations *may be* another factor that enters the complicated picture of brain function, and in this case with special reference to equivalence behavior. But this result must be regarded as no more than a suggestion for systematic study.

Taken together, the experiments of Maier (45) and the present investigator have established that there is an increase in equivalence behavior following cortical injury. Since the behavioral changes were marked, even for relatively small lesions, the method of equivalence must be regarded as a very delicate test. It remains for further experiments especially designed, perhaps on the basis of such a testable hypothesis as recently suggested by Lashley (37), to determine the neurological basis for equivalence and account for the change in equivalence behavior with cortical injury.

SUMMARY

THIS experiment was designed primarily to study the effects of cortical injury and retesting (experience) on equivalence behavior.

After it was demonstrated that no observable differences appeared in connection with variation of the situational factors (training technique and order of presentation) the effect of the major variables (operation and retesting) was evaluated by considering the following criteria of equivalence reactions: number of equivalent pairs chosen; equivalence rank order; relational responses; and preferences.

The most striking result was that operation and retesting had differential effects on equivalence reactions.

Operation tended to increase the number of equivalent pairs chosen, whereas retesting had no effect on the number of equivalent pairs chosen.

Both operation and retesting resulted in a redistribution of the equivalence choices, but the redistribution functioned in the opposite direction for each variable. Operation resulted in a significant increase in number of relational responses, whereas retesting resulted in a slight decrease in the number of relational responses.

It was shown that whenever a critical pair was regarded as equivalent, there was a marked consistency of preference for a particular card of the pair.

An extensive analysis was carried out to determine the basis for the preference. Shifting the figure-ground relations had little effect on the animal's preferences. Neither total amount of light reflected—"total brightness"—nor size of figure alone determined the preference, but some combination of the two was operative, with the former assuming the

dominant role for the first test of normal animals.

Retesting and operation had differential effects with regard to these preferences. The importance of "total brightness," which was the dominant factor for normal animals on first test, decreased with retesting to the point where it became less important than size. After operation, however, there was a slight increase in the tendency to react in terms of the total amount of light reflected.

An analysis of the group variability again provided evidence for the opposite effects of operation and retesting. The individual differences with respect to "total brightness" and size preferences decreased after operation, in contrast to the increase in individual differences that resulted from retesting.

The two behavioral criteria, number of equivalent pairs and number of relational responses were examined in relation to the various aspects of brain injury. No evidence was found of a relationship between the behavioral criteria and locus, shape, depth, and extent of lesion. There was no more than a suggestion of a relationship between the bilateral extent relations of the brain injury and the behavioral criteria, i.e., the more symmetrical lesions with respect to extent were more effective in producing behavioral changes.

The interrelations of the results, their relation to the findings of other investigators and the bearing which they may have on theoretical issues was considered.

The results of Maier's study and the one reported here show substantially the same thing, namely, that operation and retesting have opposite effects. For this reason, the conclusions that operation results in a greater importance of the

general and relative features of the training pair; and that retesting results in a decrease of the importance of the relative properties and an increase in the importance of the absolute properties of the training pair are not specific to the particular discrimination upon which the equivalence reactions are based, and thus are capable of wider generalization.

The results were used in a critique of studies involving so-called generalization and concept formation, which are regarded by some workers as evidence for

higher mental processes. In contrast to this view, the results were interpreted to mean relational responses might be a product of a very primitive type of process. It was suggested that if the term "generalization" were saved for this kind of response in terms of relational properties, it would be necessary to distinguish levels of generalization in terms of the processes underlying them. In such a case the primitive kind of generalization observed in this and other experiments should be "perceptual generalization."

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APPENDIX

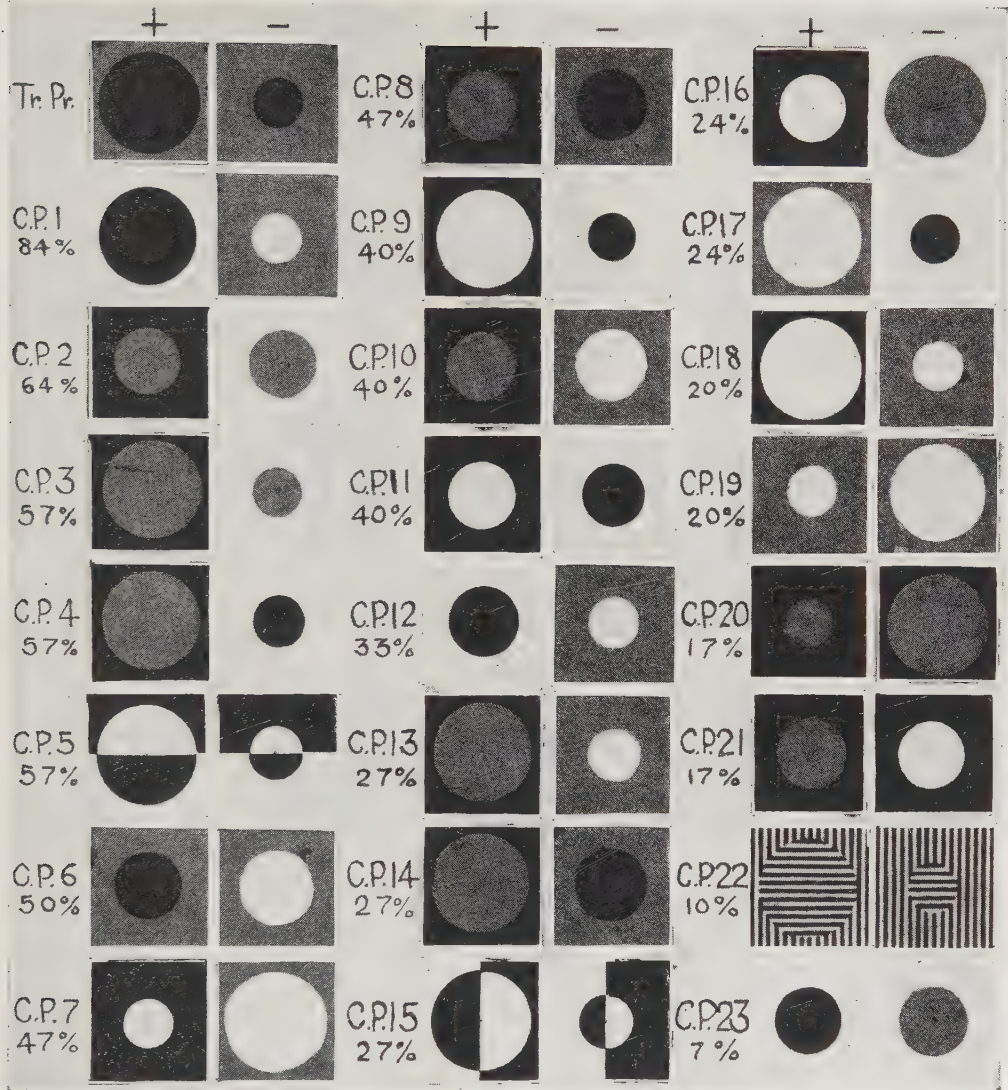


PLATE 1

The pair of cards labeled Tr. Pr. was the training pair on which the equivalence reactions were based. The pairs of cards labeled C. P. 1 through C. P. 23 constitute the critical pairs which made up the critical series. The left number (under +) of the training pair was the positive stimulus, and the left number of the critical pair was the card which was preferred. The critical pairs are arranged in the order of equivalence, and the percentage of normal animals (Normal and Post-operated Group) which regarded these pairs as equivalent on the first test is indicated. The grays on the cards used in the experiment were all alike and uniform. The cards were actually six inches square.

POST-OPERATED GROUP



PRE-OPERATED GROUP

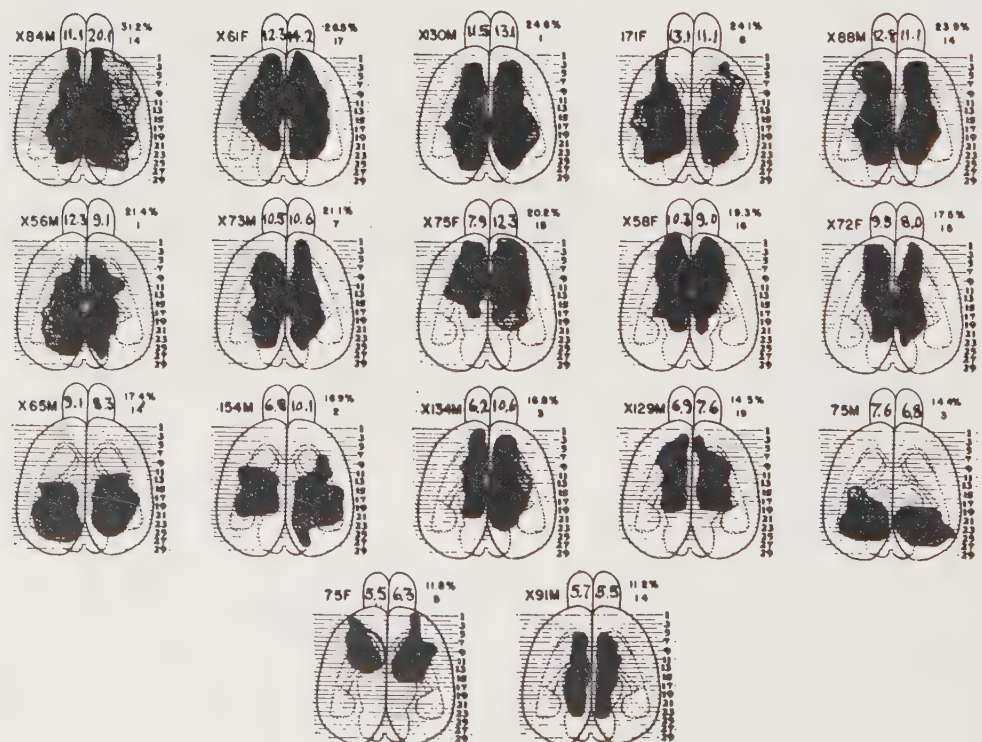


PLATE 2

Reconstruction of brain injuries of rats in the Post-operated and Pre-operated Groups. For the Post-operated Group, the total number of equivalent pairs chosen before and after operation is indicated. For the Pre-operated Group, the total number of equivalent pairs chosen on the test after operation is indicated. The black portions represent the symmetrical parts of the lesions (locus), and the stippled portions the asymmetrical parts. Only the dorsal aspects of the brains are shown because there were no cases where the lateral aspects were invaded. In all cases the total percentage of cortical destruction is indicated, as well as the percentage destruction in each hemisphere.

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